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JAMES EDWARD KEELER.

By W. W. CAMPBELL.

IT is a painful duty to record the death of Professor Keeler, on August 12, in the forty-third year of his life. The announcement came as a great shock to colleagues and friends widespread, who had seen before him a career of rarest promise. A feeling of grievous loss is borne upon us. As an investigator in astrophysics, there was no one more successful. As a director, there were none more ideal. As a companion, who was more delightful? His premature death involves a loss to astronomy and to the Lick Observatory which is incalculable.

James Edward Keeler was born in La Salle, Illinois, on September 10, 1857, of a long line of New England ancestry. The family removed to Mayport, Florida, in 1869, where Keeler prepared, by private study, for entering college. Here he acquired his fondness for astronomical observation. He established "The Mayport Astronomical Observatory" in 1875–1877 It included a quadrant, with which he observed the altitude of *Polaris* in 1875; a two-inch achromatic telescope, which he first directed to the planets and the nebulæ in December 1875; a clock, and a meridian circle, which he himself constructed and

mounted in 1877. [Keeler's original sketch of the meridian circle, and his written description of it, will be published in the *Publications of the Astronomical Society of the Pacific.*]

Keeler's "Record of Observations made at the Mayport Observatory" contains beautiful colored drawings of Jupiter, Saturn, Venus, and Mars, of double stars, and of portions of the Moon, in addition to data of a numerical character. These early sketches are worthy forerunners of his well-known drawings of many of the same objects in later years.

Mr. Keeler entered Johns Hopkins University late in the year 1877; and, following major courses in physics and German, he was graduated with the degree of A.B. in 1881.

Evidences of the high esteem in which Keeler was held by his instructors are not lacking. He largely defrayed his expenses in college by acting as assistant to some of the lecturers in the experimental courses. His private journal modestly relates the details of an evening lecture on electricity, delivered by him to a circle of young people, in President Gilman's residence. At the end of his freshman year, he accompanied Professor Hastings, as a member of Professor Holden's party from the Naval Observatory, to observe the total solar eclipse of July 29, 1878, at Central City, Colorado. His part was the modest one of making a drawing of the corona. The preliminary practice for this work, the precautions taken, and the conveniences provided, are described in his report, which is a model of scientific writing. In the spring of 1881, Professor Langley requested the Johns Hopkins University to recommend a suitable man for the position of assistant in the Allegheny Observatory. Keeler was named for and accepted the appointment, beginning work several weeks before receiving his degree. In June 1900, one of the physicists who had recommended Keeler for the Allegheny position was speaking to me of this very appointment and said: "I told Professor Langley that one of my strongest reasons for the recommendation is that Keeler doesn't claim to know everything." To the end of his life this charming trait remained unimpaired.

Professor Langley made his noted expedition to the summit of Mount Whitney, California, in the summer of 1881, to determine the value of the "Solar Constant." Mr. Keeler accompanied the expedition in the capacity of assistant, and carried out his share of the program with skill and efficiency. His work at Allegheny during the next two years was closely related to the problems arising from this expedition.

The year 1883–4 was devoted to study and travel in Europe. During the summer semester he attended lectures by Quincke, Bunsen, and Fuchs at Heidelberg. During the winter semester, in Berlin, he heard the lectures on physics by Helmholtz and Kayser, on differential equations by Runge, and on quaternions by Glan. In the Berlin physical laboratory he investigated the "Absorption of Radiant Heat by Carbon Dioxide," a problem suggested, no doubt, by his Mount Whitney experiences.

From June 1884, to April 1886, Mr. Keeler again served as assistant in the Allegheny Observatory. He afforded most efficient help to Professor Langley in his well-known researches on the lunar heat and on the infra-red portion of the solar spectrum.

Early in 1886, Mr. Keeler was appointed assistant to the Lick Trustees. He reached Mount Hamilton on April 25, and at once proceeded to establish the time service. The telegraph line to San Jose was perfected, the transit instrument, the clocks, and the sending and receiving apparatus were installed. The daily time signals were sent over the lines of the Southern Pacific Railway Company on and after January 1, 1887, north to Portland, east to Ogden, and south to El Paso. He remained in personal charge of this service until June 1891.

When the Observatory was completed and transferred to the Regents of the University of California, on June 1, 1888, Mr. Keeler was appointed to the position of Astronomer, and placed in charge of the spectroscopic work. The large spectroscope constructed for the Observatory, mainly from his designs, is an extremely efficient and convenient instrument; for visual observations it has no superior. This instrument was used with great

success in many kinds of spectroscopic work. He confirmed Vogel's observations as to the absence of telluric absorption in the spectrum of Saturn's rings. His observations of the spectrum of Uranus confirmed and extended the results obtained by Huggins and Vogel. He secured a long series of observations of the bright and dark lines in the spectra of *γ Cassiopeiae* and *β Lyrae*. He made an accurate determination of the color curve of the 36-inch objective, which is of very frequent use. His beautiful observations of the spectra of the Orion nebula and thirteen planetary nebulae mark a distinct epoch in visual spectroscopy; and his classical memoir[1] on the subject should be familiar to all spectroscopic observers. In these observations a Rowland plane-grating, 14,438 lines to the inch, was employed, in connection with the 36-inch telescope. The wave-lengths of the bright nebular lines were measured in the third and fourth order spectra—taking advantage of the fact that, other things being equal, high dispersion does not weaken the brightness of a monochromatic bright line. The wave-lengths of the principal nebular line in the fourteen nebulæ were found to vary from 5007.86 t. m. in *N. G. C.* 6790 to 5005.97 t. m. in *G. C.* 4373, with an average probable error for each object of only 0.04 t. m. The discrepancies were attributed to differences in the relative velocities of the nebulæ with reference to the solar system. The velocities themselves could not be determined directly, since the normal wave-length of the principal line was unknown, and there was no known method of reproducing this line artificially. Fortunately, the third line, hydrogen β, was bright enough in the *Orion* nebula to be compared directly with terrestrial hydrogen. The mean result of thirteen sets of such comparisons gave, for the velocity of the nebula, a recession from the solar system of 17.7 ± 1.3 kilometers per second. Correcting the observed wave-lengths of the principal line by the corresponding displacement, its normal wave-length was found to be λ 5007.05 t. m. A comparison of the observed wave-lengths of the line in the thirteen planetary nebulæ with

[1] *Publications of the Lick Observatory*, 3, 161–231.

the normal wave-length gave their velocities with reference to our system. Their values lay between −65 and + 48 kilometers. The average probable error of the velocity obtained for each nebula, depending on all the measures, was only ± 3.2 kilometers per second. The important fact was established that the velocities of the nebulæ are of the same order of magnitude as the velocities of the stars.

In a similar manner the normal wave-length of the second nebular line was found to be λ 4959.02.

Among the first objects observed with the 36-inch telescope were the planetary nebulæ and their stellar nuclei. The observers noticed that the focal length for a nebula is about 0.4 inch longer than for its stellar nucleus: a discrepancy which Professor Keeler at once explained by recalling that the star's light is yellow, whereas that of the nebula is greenish-blue. This appears to be the first recognition of the fact that a great refracting telescope is also a powerful spectroscope, for certain classes of objects, by virtue of the chromatic aberration of its objective [*Mon. Not. R. A. S.*, for 1888, p. 389; *Astr. Nach.* No. 3111].

Professor Keeler's faithful and artistic drawings of Jupiter, made in 1888–1890, with the assistance of the 36-inch equatorial, have no equals.

Professor Keeler resigned from the Lick Observatory staff on June 1, 1891, to succeed Professor Langley as Director of the Allegheny Observatory and Professor of Astrophysics in the Western University of Pennsylvania. His investigations there fully maintained the splendid reputation established for the Observatory by his predecessor. He comprehended the possibilities and limitations of his situation, and adapted himself to them. His spectroscopic researches were largely confined to the orange, yellow, and green regions of the spectrum, since they would be less strongly affected by the smoky sky for which that vicinity is famous.

The Allegheny spectroscope, constructed from his designs in 1891–2, contains a number of valuable improvements. The

ease with which it may be converted from a three-prism to a one-prism, or to a grating spectroscope, commends the plan to all. The use of three simple prisms is a departure which has been followed with advantage in many later instruments.

We may mention three noteworthy series of observations made with this instrument.

An extensive investigation of the Orion nebula and the stars immersed in it established the fact that nearly all the bright lines in the nebular spectrum have corresponding dark lines in the stellar spectra, and thus that the nebula and stars are closely related.[1]

Keeler's observations of the spectrum of Saturn's rings are of extraordinary interest. Considering the means at hand, they have never been surpassed in excellence or beauty. The classic researches of Clerk Maxwell on the composition of the rings, leading to the conclusion that they must be a cluster of little moons revolving in circular orbits, found their worthy counterpart in Keeler's spectrographic proof that every point in the ring system is moving with the velocity which a moon would have if situated at that distance from the planet. Let us not forget that these observations were made with a 13-inch telescope, in a smoky sky, which restricted the photographs to the low dispersion of the green region of the spectrum.

Professor Keeler's main piece of work at Allegheny, on the spectra of Secchi's third type stars, remains unpublished, but the measures and reductions are left in an advanced stage.

Professor Keeler was appointed to the position of Director of the Lick Observatory on March 8, 1898. He entered upon his new duties on June 1, 1898.

Without making any rearrangement of the work of the existing staff, but giving every encouragement to continue along the same lines, Professor Keeler arranged to devote his own observing time to the Crossley reflector. The story of the wonderful success with this difficult instrument is familiar to all the readers

[1] Simultaneous observations of the same objects at another observatory led to the same conclusion.

of the ASTROPHYSICAL JOURNAL. He was quick to recognize that this instrument was not in condition to produce satisfactory results. He proceeded energetically to make one change after another, and to overcome one difficulty after another, until at the end of five months he was ready to submit it to trial. On November 14, he secured a splendid negative of the Pleiades, and on the 16th a superb negative of the Orion nebula. Having satisfied himself of the enormous power of the reflector in nebular photography, he entered upon the program of photographing the brighter Herschel nebulæ. More than half of the subjects on his program have been satisfactorily photographed. The Observatory possesses a set of negatives of the principal nebulæ which is priceless, and unequaled.

These photographs record, incidentally, great numbers of new nebulæ. A conservative estimate places the number within reach of the Crossley reflector at 120,000.

It had previously been supposed that the great majority of nebulæ were irregular in form, and that only a few were spirals. These photographs have recorded more spiral nebulæ than irregular ones. This discovery bears profoundly upon the theory of the cosmogony, and must be considered as of the first order.

It is time to speak of Professor Keeler's work as Director. I but faintly reflect the views of every member of the staff, and, indeed, of all who have been interested in the work of the Lick Observatory, when I say that his administration was completely successful. He cherished and promoted ideal conditions in this ideal place. He made a success of his own work, in a splendidly scientific manner; and he saw to it that everyone had every possible opportunity to do the same. No member of the staff was asked to sacrifice his individuality in the slightest degree. Nor were demands made for immediate results. The peace of mind of the investigator, so absolutely required for complete success, was full and undisturbed. Withal, Professor Keeler's administration was so kind and so gentle—and yet so effective—that the reins of government were seldom seen and never felt.

The elements of his successes are simple, and plainly in view. His openness and honesty of character, his willingness and quickness to see the other man's point of view, his strong appreciation of the humorous, as well as the serious, and, above all, his abounding good sense—these traits made his companionship delightful and charming.

Scientifically, Professor Keeler never groped aimlessly in the dark. He would not attack a problem until he had as fully as possible comprehended its nature, and the requirements for success. With the plan of attack completely considered, the execution of his plans usually involved little loss of time. The Crossley reflector has afforded a case in point. It was seldom necessary for him to repeat any part of his work.

His published papers have a completeness, a ripeness, and a finish rarely seen. A complete list of his published writings is appended.

The honorary degree of Sc.D. was conferred upon Professor Keeler in 1893 by the University of California. The Rumford Medal was bestowed upon him in 1898 by the American Academy of Arts and Sciences, and the Henry Draper Medal in 1899 by the National Academy of Sciences. He was a member of the National Academy of Sciences; an Associate of the American Academy of Arts and Sciences; a Fellow and Foreign Associate of the Royal Astronomical Society; a Fellow of the American Association for the Advancement of Science; a member and officer of the Astronomical and Astrophysical Society of America; an honorary member of the Toronto Astronomical and Physical Society; the president of the Astronomical Society of the Pacific; a member of the Washington Academy of Sciences; and various other organizations. He was an associate editor of *Astronomy and Astro-Physics* during 1893 and 1894, and editor (with Professor George E. Hale) of the ASTROPHYSICAL JOURNAL from 1895 to the time of his death.

It appears that he had been a mild sufferer from heart weakness for many years. It is feared that on Mt. Hamilton he worked beyond his strength. His weakness seems to have

developed rapidly this year: a cold contracted in June he could not throw off. He left the Observatory on July 30, with no anxiety, to secure medical treatment in San Jose, and to spend a prospective vacation in northern California. Increasing difficulty in breathing led him to seek skilled assistance in San Francisco, on August 10. The dangerous condition of his heart was realized on the next day; and on the twelfth a stroke of apoplexy proved fatal.

It is known that Professor Keeler had planned his work with the Crossley Reflector far into the future. It is sad to relate that a small spectrograph, which he was most anxious to employ on certain interesting objects, was completed on the day of his leaving the Observatory. Arrangements have been made for carrying out his program.

The absence of one so old in experience and so ripe in judgment will be most seriously felt at the Lick Observatory, and throughout the profession.

Professor Keeler married Miss Cora S. Matthews, at Oakley Plantation, Louisiana, on June 16, 1891. Of her great sorrow, and of the grievous loss to the two children, it would be futile to speak. Their departure leaves the mountain inexpressibly sad.

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A LIST OF NINE STARS WHOSE VELOCITIES IN THE LINE OF SIGHT ARE VARIABLE.

By W. W. CAMPBELL and W. H. WRIGHT.

THE following nine spectroscopic binaries, discovered with the Mills spectrograph, are additional to the sixteen already announced.

The results expressed in integers are only approximate, and in most cases will be slightly changed by the final measures and reductions.

12 PERSEI ($\alpha = 2^h\ 36^m$; $\delta = +39^\circ\ 46'$).

The binary character of this star was discovered in January, from the second spectrogram. The spectra of both components are visible on the first three plates, and are not very unlike. On the last plate the two spectra appear to be coincident.

Date		Velocities
1899	Dec. 19	−42 km and ± 0 km
1900	Jan. 22	− 3 " − 54
	Jan. 26	−11 " − 43
	Aug. 7	−27

The velocity of the system is about −25 km per second.

ξ URSAE MAJORIS ($\alpha = 11^h\ 13^m$; $\delta = +32^\circ\ 06'$).

The principal component of this well-known double star has a variable velocity in the line of light. ξ *Ursae Majoris* is therefore a triple system. The visible system is interesting, historically, as having been the first one to show orbital motion, the two visible components forming a close and rapidly revolving system ($a = 2''.5$, $P = 60$ years). It has been observed with the micrometer very frequently since the beginning of the century, but no evidences of perturbative influences have been revealed by the measurements.

	Date	Velocity
1897	Feb. 23	− 8.4 km
	April 8	−15
1899	Feb. 22	−11.5
	April 5	−14.1
1900	Feb. 26	−21.9
	Mar. 9	−18.4
	Mar. 12	−19
	Mar. 14	−21.6
	Mar. 20	−20
	May 8	−18

The variable velocity was discovered early in March, from the fifth plate.

The spectrograms obtained in 1897 are rather poor, and will probably not be needed in the final discussion of the motion.

93 LEONIS ($\alpha = 11^h\ 43^m$; $\delta = +20^\circ\ 46'$).

The first two plates of this star were underexposed, but the discordance of eight kilometers afforded strong suspicion of its variable velocity. Two late plates confirmed the fact of its variability.

	Date	Velocity
1900	Jan. 10	+22 km
	Jan. 16	+14 ±
	Apr. 9	−16
	May 14	+16

d BÖOTIS ($\alpha = 14^h\ 06^m$; $\delta = +25^\circ\ 34'$).

	Date	Velocity
1900	Mar. 27	+79 km
	April 4	+ 3
	April 9	+11
	April 17	+60 ±

The variable velocity was discovered from the second plate

β SCUTI ($\alpha = 18^h\ 42^m$; $\delta = -4^\circ\ 51'$).

	Date	Velocity
1899	May 15	−17 km
	June 11	−11
1900	April 17	−28
	April 23	−29
	May 14	−32
	July 18	−31

The variable velocity was discovered from the third plate.

113 HERCULIS ($\alpha = 18^h\ 50^m$; $\delta = +22^\circ\ 32'$).

Date		Velocity
1900	June 5	−35 km
	July 9	−21
	July 17	−19
	July 31	−16

The variation was discovered from the second plate,

2 SCUTI ($\alpha = 18^h\ 37^m$; $\delta = -9^\circ\ 09'$).

Date		Velocity
1899	June 14	−49 km
	June 19	−50
	July 3	−45
1900	June 27	−40
	July 3	−38
	Aug. 1	−49
	Aug. 12	−38

The lines in this star's spectrum are rather broad, and cannot be measured very accurately. In addition, the third plate was underexposed; and the range of five kilometers in the approximate results for the first three plates afforded only a slight suspicion of vriability. Its reality was established from the fourth plate.

η ANDROMEDAE ($\alpha = 0^h\ 52^m$; $\delta = +22^\circ\ 52'$).

Two components seem to be visible in the spectrograms of this star. The results for the principal component are:

Date		Velocity
1899	Oct. 24	−25 km
	Oct. 31	−26
1900	July 24	−12
	Aug. 8	+ 2
	Sept. 9	− 2

The two component spectra appear to be practically coincident in the spectrogram of 1900, July 24.

κ PEGASI ($21^h\ 40^m$; $\delta = +25^\circ\ 11'$).

It will be recalled that this is the visual binary star having the shortest known period ($a = 0''.4$, $P = 11$ years). It was

discovered by Burnham in 1880 with the 18½-inch telescope, and is one of the difficult stars on his list. The two components are described as yellowish, and of magnitudes about 4½ and 5. The present distance of the components is less than 0″.2, in position angle 260° ±. It is not possible to photograph their spectra separately with the Mills spectrograph.

One of the components of this double star — probably the component whose spectrum is the stronger in the *Hγ* region — is a spectroscopic binary. *κ Pegasi* is therefore a triple system of great interest. The observations secured are as follows:

Date		Velocity
1896	Aug. 31	−43 km
1899	July 17	−41
1900	Aug. 6	+35
	Aug. 7	+27
	Aug. 8	−16
	Aug. 12	+35
	Aug. 21	−45
	Aug. 22	−34

The variable velocity was discovered from the third plate. The period seems to be about six days.

Changes in the appearance of the spectrum occur, but their source has not yet been traced.

[NOTE BY W. W. C.— Mr. Wright was in charge of the work with the Mills spectrograph during my connection with the Crocker Eclipse Expedition to Georgia, from March to late in July. While following the regular program of observation, he detected the variable velocities of the stars *ξ Ursae Majoris*, *d Böotis*, *β Scuti*, *113 Herculis*, and *2 Scuti*, as described above; and the credit for these five discoveries belongs to him.]

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA,
September 12, 1900.

THE VISIBLE SPECTRUM OF *NOVA AQUILAE.*

By W. W. CAMPBELL.

THE new star in *Aquila*, discovered by Mrs. Fleming in July 1900, by means of its spectrum on the Draper Memorial photographs, was observed by Mr. Wright and myself on the evening of August 27. A 60° simple prism spectroscope was used in connection with the 36-inch refractor.

The visible spectrum consisted of extremely faint continuous light in the green, and of three bright bands in the positions of the three principal nebular lines. The relative intensities of the three bands agreed approximately with the corresponding intensities in the well-known nebular spectra. The bands were not monochromatic, but on the contrary were very broad, perhaps fully twice as broad as the bands in the nebular spectrum of *Nova Aurigae* in August 1892.

The present observations confirm the Harvard College Observatory observations that the spectrum of *Nova Aquilae* is nebular.

September 17, 1900.

THE VARIABLE STAR *7792 SS CYGNI.*

THIRD PAPER, 1899–1900.

By J. A. PARKHURST and ZACCHEUS DANIEL.

THE past year's observations of this variable star (discovered by Miss Wells from the Harvard photographs, and announced in *H. C. O. Circular* No. 12) have revealed several interesting points in its manner of variation, some of them as unexpected as they were remarkable. After two and a half years of alternating "long" and "short" maxima of the same general type, differing only in duration, the star violated all traditions by passing a maximum of an entirely different type, whose reality might be doubted were it not for the fact that it was attested by the accordant results of four different observers. This was followed by two "long," one "short," and one "long" maximum, of the ordinary type, closing the chapter at the date of writing. We have no record like this in the annals of variable star work.

The former papers in this series[1] covered the interval between December 1896 and January 1899. The present paper continues the work till August 1900, using the same comparison stars (with one exception) and light scale which are given in Table I. In this table, following the letter and the coördinates of the star from the variable, there are three columns headed "Magnitude." In the first column, headed "Vis." are given the magnitudes on the visual scale, defined by agreement with the photometric scale at 8.0 magnitude, and the assumption of 12.8 as the limit of the 6-inch reflector. The next column gives the photometric magnitudes of nine of the stars, kindly supplied by Professor E. C. Pickering, and the third column the *B. D.* magnitudes of such of the stars as are contained in that catalogue. Table II gives the reduction from the visual to the photometric scale, using the magnitudes of the

[1] *Popular Astronomy*, 6, 156 and 7, 138.

visual scale as the argument. The accompanying chart, Fig. 1, shows the stars within 1 minute of the variable in R. A. and 10′ in Declination.

TABLE I.

COMPARISON STARS FOR *7792 SS CYGNI.*

R. A. $21^h\ 38^m\ 46^s.2$, Dec. $+43^\circ\ 7'\ 35''$ (1900).

Star	Coör. from V.		Magnitude			B. D. No.
	R. A.	Dec.	Vis.	Phot.	B. D.	
	s					
k	+ 3.5	— 0.8	12.4			
h	— 8.0	— 1.1	11.81			
o	+ 3.8	+ 5.4	11.58	12.14		
q	— 5.1	— 5.3	11.44			
g	— 30.7	— 2.4	11.41			
m	— 5.9	+ 4.2	11.30	11.77		
e	— 34.8	— 0.7	10.86			
d	— 14.5	— 1.4	10.55	10.92		
p	+ 19.5	+ 6.4	10.54	10.90		
n	— 7.6	+ 7.7	10.51			
a	— 21.3	— 1.0	9.43	9.62	9.2	+42°4186
c	+ 0.3	+ 8.0	9.27	9.39	9.2	43 4020
z	— 55	+27	9.07		8.7	43 4012
w	+100	+13.3	8.86	8.90	8.6	43 4030
b	+ 27.0	— 0.2	8.46	8.50	8.3	42 4190
l	+123	— 8.7	7.92	8.00	8.5	42 4195

TABLE II.

REDUCTION FROM VISUAL TO PHOTOMETRIC SCALE.

Visual Scale	Reduction
8.0	0.0
9.0	+0.13
10.0	+0.28
11.0	+0.45
12.0	+0.66

In Table III we have given the observed magnitudes between February 10, 1899, and August 3, 1900. For economy of space only the Julian dates are given in the first column, the decimals

being in Greenwich Mean Time. In the second and third columns, headed Vis. and Ph., are given the magnitudes by the visual and photometric scales, respectively, followed by a colon when the observation was doubtful. In the fourth column is

R. A. $21^h\ 38^m\ 46^s$, Dec. $+43°\ 7'.6$ (1900).

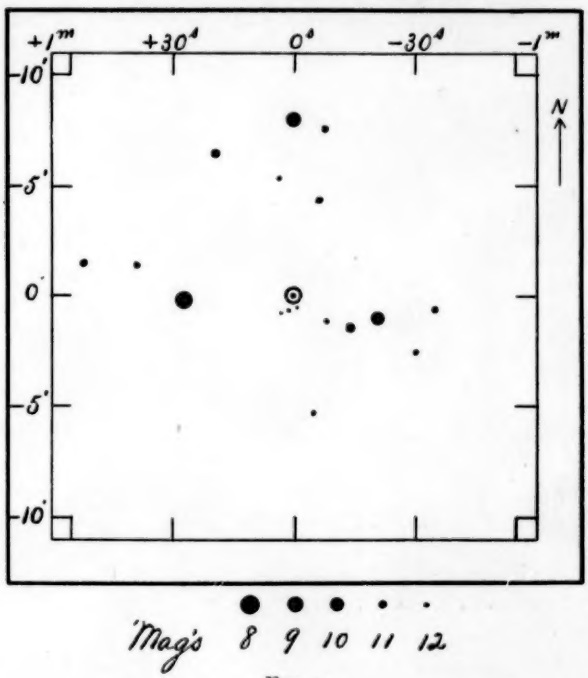


FIG. 1.

the initial of the observer. The table contains 286 observations. Of these 131 were made by Daniel, 71 with the 10-inch Clark refractor of the Bucknell Observatory at Lewisburg, Pa., and 60 with his 4-inch refractor. Of Parkhurst's 155 observations, 149 were made with his 6-inch reflector, 5 with the Yerkes 12-inch, and 1 with the Yerkes 40-inch refractor. In spite of this variety of instruments, the magnitudes are quite accordant, the simultaneous observations usually agreeing within 0.1 magnitude.

TABLE III.

OBSERVED MAGNITUDES OF *7792 SS CYGNI.*

D = Zaccheus Daniel, P = J. A. Parkhurst.

Julian Day	Magnitude		Obs.	Julian Day	Magnitude		Obs.
	Vis.	Ph.			Vis.	Ph.	
2414696.53	11.44	11.98	D	2414841.68	8.66	8.75	D
4702.00	11.37	11.89	P	42.65	8.93	9.05	P
18.96	11.3 :	11.8 :	P	42.67	8.81	8.91	D
19.95	11.26:	11.76:	D	44.65	9.10	9.24	P
20.97	10.90	11.33	P	45.63	9.24	9.40	P
21.96	8.41	8.46	P	45.64	9.11	9.25	D
26.96	9.83	10.08	P	46.63	9.65	9.88	P
33.96	11.30	11.81	P	46.67	9.35	9.53	D
55.89	11.37	11.89	D	47.62	9.65	9.88	P
61.92	11.37	11.89	P	47.65	9.73	9.97	D
66.92	11.40	11.93	P	48.65	10.15:	10.46:	D
74.72	11.37:	11.89:	D	50.71	11.05	11.51	D
76.70	9.50	9.70	P	53.62	11.15	11.63	P
76.90	9.24	9.40	P	53.64	11.16	11.64	D
77.90	8.50	8.56	P	54.62	11.15	11.63	P
79.67	8.25	8.28	P	56.60	11.25	11.75	P
81.71	8.46	8.52	D	68.67	11.22	11.71	D
84.66	8.34	8.38	D	72.60	11.37	11.89	P
85.88	8.86	8.97	P	73.65	11.37	11.89	D
86.67	8.58	8.66	D	76.64	11.37	11.89	P
88.65	8.95	9.07	D	77.63	11.28	11.79	P
90.67	9.56	9.77	D	79.60	11.35	11.87	P
93.65	10.79	11.20	P	79.64	11.32	11.83	D
4796.87	11.44	11.98	P	80.58	11.20	11.69	P
4804.65	11.36	11.88	P	81.60	11.26	11.76	P
08.65	11.32	11.84	D	82.59	11.18	11.67	P
09.65	11.34	11.86	P	83.58	11.26:	11.76:	P
13.66	11.34	11.86	P	84.58	11.23	11.73	P
18.65	11.39	11.92	P	85.58	11.30	11.81	P
18.71	11.30:	11.81:	D	86.58	11.30	11.81	P
21.63	11.20	11.69	P	87.58	11.30	11.81	P
22.64	11.37	11.89	D	88.59	11.30	11.81	P
25.64	11.3 :	11.8 :	P	89.57	10.55	10.92	P
26.64	11.30:	11.81:	D	89.60	10.36	10.70	P
27.62	11.4 :	11.9 :	P	90.57	8.63	8.71	P
29.63	11.44	11.98	P	91.58	8.50	8.56	P
30.65	11.39	11.92	P	93.58	8.51	8.57	P
35.63	11.44	11.98	P	95.58	8.50	8.56	P
35.66	11.37	11.89	D	96.58	8.53	8.60	P
36.67	11.13	11.61	D	97.58	8.60	8.68	P
36.71	11.34	11.86	P	4899.58	8.71	8.80	P
37.65	10.45	10.80	D	4901.58	8.89	9.00	P
38.62	8.45	8.51	P	02.60	8.85	8.96	P
38.63	8.66	8.75	D	04.58	9.55	9.76	P
39.67	8.61	8.69	D	06.60	10.77	11.17	P
40.67	8.61	8.69	D	09.59	11.22	11.71	P
2414841.67	8.63	8.71	P	2414909.67	11.30	11.81	D

TABLE III.—*Continued.*

Julian Day	Magnitude		Obs.	Julian Day	Magnitude		Obs.
	Vis.	Ph.			Vis.	Ph.	
2414928.53	11.34	11.86	D	2414995.54	9.92	10.18	D
28.56	11.30	11.81	P	96.51	10.22	10.53	P
30.55	11.28	11.79	P	97.51	10.85	11.27	P
32.57	11.33	11.85	P	97.57	10.51	10.87	D
35.5	11.30	11.81	P	4998.50	11.03	11.49	D
37.56	11.4 :	11.9 :	P	5001.66	11.37	11.89	D
40.63	11.37	11.89	P	02.54	11.37	11.89	D
42.66	11.44	11.98	D	04.54	11.52	12.07	D
46.54	11.37	11.89	P	05.60	11.42	11.95	D
46.66	11.44	11.98	D	08.51	11.35	11.87	P
48.66	11.42	11.95	D	08.52	11.58	12.15	D
49.54	11.33	11.85	P	09.51	11.32	11.83	P
49.64	11.44	11.98	D	10.58	11.44	11.98	P
50.64	11.37	11.89	D	12.53	11.28	11.79	P
51.54	11.26	11.76	P	14.50	11.44:	11.98:	P
51.65	11.37	11.89	D	16.51	11.32	11.83	P
52.50	10.87	11.29	P	17.51	11.32	11.83	P
52.55	10.95	11.39	P	18.51	11.21	11.70	P
52.65	10.91	11.34	D	21.51	8.71	8.80	P
56.54	8.60	8.68	P	22.51	8.65	8.74	P
57.51	8.86	8.96	P	23.51	8.55	8.62	P
57.60	8.79	8.89	D	24.51	8.50	8.56	P
58.54	9.09	9.23	P	25.50	8.50	8.56	P
59.50	9.18	9.34	P	26.55	8.46	8.52	D
61.67	9.99	10.27	D	27.51	8.52	8.59	P
62.58	10.55	10.92	P	28.51	8.65	8.74	D
63.52	10.88	11.31	P	29.54	8.85	8.95	D
64.50	11.23	11.73	P	30.54	8.83	8.93	D
65.52	11.20	11.69	P	32.51	8.93	9.05	D
65.61	11.16	11.64	D	41.51	11.37:	11.89:	D
67.53	11.16	11.64	P	42.52	11.30:	11.81:	P
79.54	11.25	11.75	P	44.51	11.25	11.75	P
82.56	10.32	10.65	D	47.53	11.37:	11.89:	D
83.50	9.99	10.27	D	51.52	11.30	11.81	P
84.50	9.85	10.11	D	52.52	11.37	11.89	D
84.50	10.05	10.34	P	53.51	11.32	11.83	D
85.50	9.68	9.91	P	56.52	11.37	11.89	D
85.63	9.77	10.01	D	66.50	11.37	11.89	D
86.50	9.49	9.69	P	66.54	11.30	11.81	P
86.52	9.77	10.01	D	67.53	11.37	11.89	P
87.49	9.18	9.34	D	69.51	11.47	12.01	D
87.50	9.35	9.53	P	70.52	11.37	11.89	D
87.55	9.23	9.39	D	70.56	11.30	11.81	P
88.57	9.23	9.39	P	76.5	11.28	11.79	P
89.58	8.87	8.98	D	77.51	11.42	11.95	D
90.52	8.64	8.72	P	77.55	11.3 :	11.8 :	P
91.53	8.94	9.06	D	78.51	11.42	11.95	D
92.54	9.17	9.32	P	81.91	11.22	11.71	D
93.55	9.24	9.40	P	82.50	10.8 :	11.2 :	D
94.51	9.43	9.62	P	85.96	8.46	8.52	P
2414995.52	9.55	9.76	P	2415086.93	8.46	8.52	D

TABLE III.—*Continued.*

Julian Day	Magnitude		Obs.	Julian Day	Magnitude		Obs.
	Vis.	Ph.			Vis.	Ph.	
2415087.92	8.46	8.52	D	2415191.66	11.30	11.81	P
89.91	8.66	8.75	D	91.70	11.27	11.77	D
90.93	8.71	8.80	D	92.60	11.37	11.89	D
93.94	8.85	8.96	P	94.65	11.37	11.89	D
5095.94	10.30	10.63	P	94.66	11.39	11.92	P
5100.86	11.14	11.62	D	95.68	11.37	11.89	D
02.81	11.37	11.89	D	96.62	11.37	11.89	P
13.79	11.35	11.87	D	96.64	11.37	11.89	D
29.77	11.37	11.89	D	96.84	11.30	11.81	P
34.75	11.27	11.77	D	97.62	11.32	11.83	D
35.73	9.32	9.49	D	97.62	11.37	11.89	P
36.86	8.68	8.77	D	98.61	11.3 :	11.8 :	P
36.87	8.59	8.67	P	5199.62	11.32	11.83	D
37.74	8.66	8.75	D	5200.64	8.78	8.88	P
38.88	8.82	8.92	D	00.71	8.76	8.86	D
39.85	9.00	9.13	D	01.64	8.45	8.50	D
39.86	9.01	9.14	P	02.62	8.36	8.40	D
41.87	9.87	10.13	P	03.60	8.31	8.35	D
43.87	10.66	11.05	D	04.62	8.31	8.35	D
44.80	10.97	11.41	D	05.60	8.37	8.42	P
45.82	11.37	11.89	D	07.67	8.56	8.82	D
49.87	11.44	11.98	D	09.64	8.56	8.63	P
60.70	11.37	11.89	D	11.62	8.69	8.78	P
60.83	11.23	11.72	P	11.63	8.76	8.86	D
65.78	11.37	11.89	D	12.60	8.62	8.70	P
66.81	11.37	11.89	D	13.64	9.06	9.19	D
68.83	11.35	11.87	P	14.61	9.27	9.44	D
70.68	11.42	11.95	D	15.67	9.53	9.73	D
74.66	11.37	11.89	P	16.64	9.99	10.27	D
75.66	11.30	11.81	P	17.60	10.44	10.79	D
76.79	11.42	11.95	D	17.64	10.46	10.81	P
80.73	11.32	11.83	D	18.67	10.86	11.28	D
81.73	11.32	11.83	D	19.61	11.15	11.63	D
83.61	<10.5 :	<10.9 :	P	22.65	11.37	11.89	D
84.75	11.44	11.98	P	24.65	11.37	11.89	D
85.73	11.34	11.86	P	28.63	11.47	12.01	D
86.62	11.44	11.98	P	29.65	11.37	11.89	P
87.62	11.3 :	11.8 :	P	31.66	11.52	12.07	D
88.64	11.33	11.84	P	32.60	11.44	11.98	D
89.64	11.37	11.89	P	33.63	11.42	11.95	D
90.69	<10.5 :	<10.9 :	P	34.66	11.47	12.01	D
2415190.73	11.32	11.83	D	2415235.62	11.47	12.01	D

Fig. 2 gives a general view of the light changes, the time interval covering one of the double periods, including a "short" and a "long" maximum. The magnitudes are expressed on the visual scale, and the time coördinate is chosen rather short in order to include in one figure the complete cycle of light

changes. As in previous years, the star remained quiet at normal light, 11.34 magnitude, for about three fourths of the time, then rose quickly to maximum at 8.5 magnitude; the greater part of the rise, from 11th to 9th magnitude, occupying nineteen hours. The decline was much slower than the rise, both after long and short maxima. The star was above normal light for twelve days at the short, and nineteen days at the long maxima. The periods of normal light averaged forty and forty-four days after the short and long maxima respectively. The form of the

LIGHT CHANGES OF *SS Cygni*.

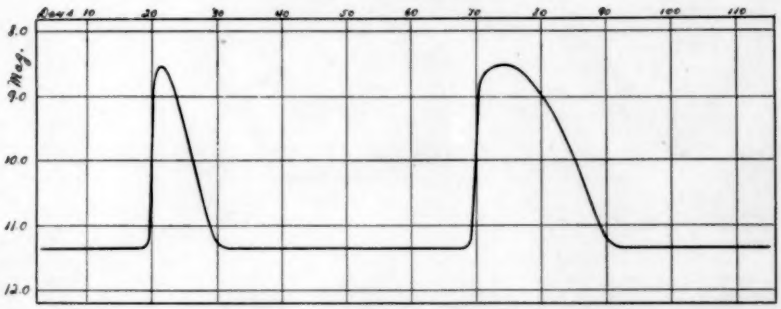


FIG. 2.

light curves was such that the times of maxima were usually uncertain by a considerable fraction of a day, which amounted to a whole day at the long maxima. The rise, however, was so prompt that the time of passing 9.35 magnitude (the mean of the comparison stars *a* and *c*) could usually be fixed within one tenth of a day. In the discussion that follows this time is called T_0.

Table IV gives a résumé of the results for the entire period during which we have had the star under observation. A sufficient explanation of the contents is given in the headings of the columns, except for the number of the epoch in the second column. For maxima No. 3 to 19, inclusive, the long and the short type alternated without a break in the order. For the purpose of discussion, the different types are numbered and considered separately, giving eight short and seven long maxima in the set.

TABLE IV.

RESULTS FROM DECEMBER 1896 TO JULY 1900.

No.	Epoch	Rise began	T_0	Maximum	Above normal	Reached normal	Remained at normal
		J. D.	J. D.		days	J. D.	days
1	(long)	3939	3940	'97, Jan. 20 3945	20	3959	44
2	(short)	4003	4004.5	Mar. 22 4006	13	4015.9	22
3	0 (short)	4038	4039.0	April 25 4040	11	4049.0	30
4	0 (long)	4079	4080.4	June 8.6 4084.6	19	4098.0	46
5	1 (short)	4144	4145.4	Aug. 10.1 4147.1	13	4157.0	37
6	1 (long)	4194	4196.2	Oct. 1.4 4200.4	20	4214.1	44
7	2 (short)	4258	4259.5	Dec. 2 4261	13	4271.5	34
8	2 (long)	4306	4307.2	'98, Jan. 21.4 4311.4	19	4325.4	44
9	3 (short)	4369	4370.0	Mar. 22.6 4371.6	13	4382	45
10	3 (long)	4427.3	4427.8	May 22.2 4432.2	20.1	4447.4	43
11	4 (short)	4490	4491.4	July 21.8 4492.8	11	4501.0	36
12	4 (long)	4537	4538.4	Sept. 9.6 4542.6	19	4556	48
13	5 (short)	4604.0	4605.1	Nov. 13.0 4607.0	11.1	4615.1	45.7
14	5 (long)	4660.8	4661.8	'99, Jan. 10.5 4665.5	18.4	4679.2	41.6
15	6 (short)	4720	4721.6	Mar. 9 4723	11	4731	44
16	6 (long)	4775	4776.8	May 5 4780	20	4796	41
17	7 (short)	4837.0	4838.0	July 3.8 4839.8	14.0	4851	38
18	7 (long)	4889.0	4890.0	Aug. 26.6 4893.6	19	4908	44
19	8 (short)	4952.2	4953.0	Oct. 26.8 4954.8	12.4	4965.0	15
20	anomalous	4980	4987.5	Dec. 2.2 4991.2	19	4999	21
21	(long)	5020	5021	'00, Jan. 7 5027	19	5039	43
22	(long)	5082	5083	Mar. 8 5087	20	5102	33
23	(short)	5135.0	5135.7	Apr. 27 5137	11.0	5146.0	53.5
24	(long)	5199.5	5200.5	July 3.2 5204.2	21.5	5221.0	

It will be noticed that this cycle was preceded by two short maxima in succession, Nos. 2 and 3, and closed by the anomalous maximum No. 20 (which will be considered later) followed by two long maxima in succession. It is possible that this is only half a complete cycle which will be finished when the

SS Cygni 1897–1900.

NORMAL CURVES FROM LONG AND SHORT MAXIMA 1 TO 8.

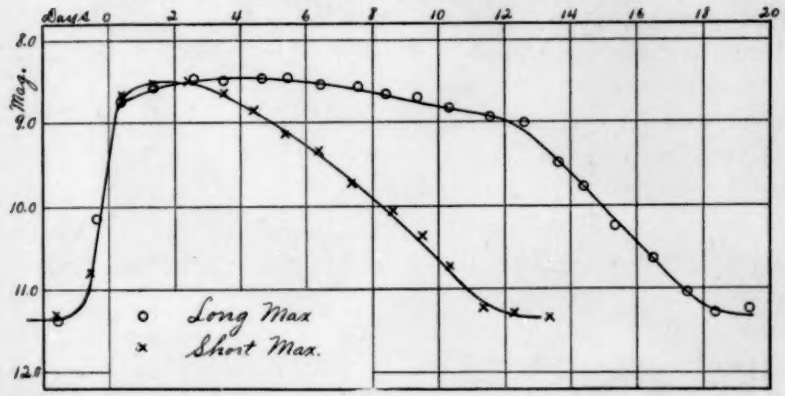


FIG. 3.

present set is ended by a repetition of two successive short maxima like Nos. 2 and 3, but this can be settled only by assiduous observations in the future.

NORMAL CURVES.

Considering maxima Nos. 3 to 19 as forming a complete set, the observations, 619 in number, were used to form normal curves by arranging them in order of the time (T) elapsed from the T_0 of each maximum. Table V, giving the results for the short and long maxima, was formed by taking daily means of the T's and the corresponding magnitudes, which are expressed both on the visual and photometric scales. A graphic representation of these results is given in Fig. 3. In both types the rise begins suddenly and proceeds with the same rapidity. The crest of the wave occurs at 2.0 days after T_0 for the short, and at 5.0 days for the long maxima. The fall from magnitude 9.0 to 11.0 taking place at the same rate, occupies about six days in

each type. The sharp turns in the curve at the beginning and end of maximum are peculiar to this type of variable.

The anomalous maximum of November-December 1899 deserves special attention, being utterly unlike the usual types. The difference appears by comparing the curves in Fig. 3 with that in Fig. 4, taken, by the courtesy of the editor, from the January 1900 *Popular Astronomy*. The reality of the curve in Fig. 4 is attested by the accordant results of the four observers, David Flanery, of Memphis, Tenn., and William E. Sperra, then of Randolph, O., besides the writers.

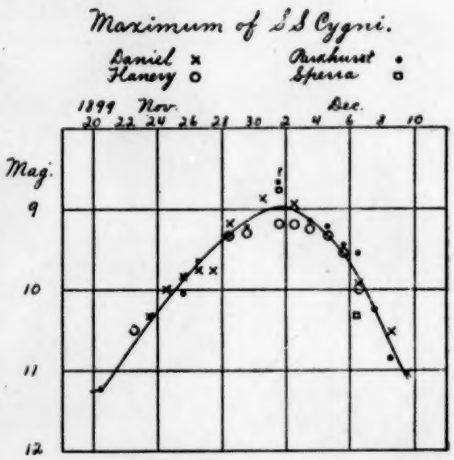


FIG. 4.

The behavior of the star during its periods of normal light is but slightly less important than the maximum curves, and deserves close inspection. In Fig. 2 the normal light is drawn as a uniform horizontal line at magnitude 11.34. As the accuracy of this conclusion has been questioned the following investigation was made. Means were first formed of the magnitude for each period of normal light separately, between maxima Nos. 3 and 20. The results, expressed both in visual and photometric magnitudes, are shown in Table VI, with the number of observations on which each mean depends. The brightest mean is 11.21, the faintest 11.40, the general mean 11.34. The average difference between each quantity and the general mean is 0.05, showing that the several periods of normal light have substantially the same magnitude. A test of the variation during the separate periods is shown in Table VII. For this purpose the magnitudes are grouped in five-day intervals, and the mean of each interval, numbered 1 to 9, is given;

TABLE V.

NORMAL POINTS FROM DAILY MEANS.

No.	Short maxima				Long maxima			
	T	Magnitude		No. obs.	T	Magnitude		No. obs.
		Vis.	Pho.			Vis.	Pho.	
1	−2.76	11.28	11.79	3	−2.47	11.38	11.91	3
2	−1.58	11.30	11.81	8	−1.46	11.32	11.83	9
3	−0.57	10.80	11.21	11	−0.36	10.18	10.49	10
4	+0.35	8.67	8.76	9	+0.42	8.77	8.87	10
5	1.33	8.53	8.60	8	1.42	8.59	8.67	12
6	2.38	8.51	8.57	7	2.57	8.48	8.54	8
7	3.49	8.66	8.75	7	3.47	8.51	8.57	10
8	4.42	8.85	8.96	10	4.60	8.48	8.54	7
9	5.30	9.17	9.32	8	5.46	8.46	8.52	5
10	6.38	9.37	9.55	6	6.47	8.57	8.64	6
11	7.39	9.74	9.98	8	7.52	8.59	8.67	10
12	8.61	10.03	10.32	9	8.38	8.66	8.75	5
13	9.53	10.36	10.70	8	9.43	8.70	8.79	9
14	10.30	10.74	11.10	6	10.32	8.83	8.93	4
15	11.27	11.22	11.71	4	11.51	8.95	9.07	8
16	12.27	11.31	11.82	3	12.53	9.01	9.14	8
17	+13.38	11.36	11.88	2	13.60	9.48	9.68	5
18	.....	....	....	..	14.43	9.77	10.01	8
19	.....	....	....	..	15.38	10.26	10.58	8
20	.....	....	....	..	16.48	10.63	11.01	11
21	.....	...	....	..	17.50	11.06	11.52	6
22	.....	...	....	..	18.27	11.31	11.82	2
23	.....	....	....	..	+19.44	11.24	11.74	7
				117				171

TABLE VI.

MAGNITUDES DURING THE SEPARATE PERIODS OF NORMAL LIGHT.

Between maxima	Magnitude		No. of obs.	Between maxima	Magnitude		No. of obs.
	Vis.	Pho.			Vis.	Pho.	
3– 4	11.24	11.74	8	11–12	11.40	11.93	16
4– 5	11.26	11.76	57	12–13	11.40	11.93	20
5– 6	11.32	11.83	58	13–14	11.38	11.91	21
6– 7	11.31	11.82	37	14–15	11.36	11.88	7
7– 8	11.30	11.81	5	15–16	11.36	11.88	5
8– 9	11.40	11.93	15	16–17	11.35	11.87	16
9–10	11.38	11.91	9	17–18	11.25	11.75	18
10–11	11.39	11.92	18	18–19	11.34	11.86	17
				19–20	11.21	11.70	4

the last two columns combining the like-numbered intervals for the three years, and the last line combining all the intervals for each year separately. It may be stated, as the conclusion, that these observations furnish no evidence of a variation in light during a single normal period, or of a difference in the separate periods.

TABLE VII.

PERIODS OF NORMAL LIGHT.

Means of 5-day intervals.

Intervals	1897	1898	1899	Mean Mag.	
				Vis.	Pho.
1	11.26	11.42	11.28	11.32	11.83
2	26	35	31	31	82
3	29	46	29	35	87
4	27	37	22	29	80
5	26	38	35	33	84
6	32	36	30	33	84
7	36	39	35	37	89
8	35	43	34	37	89
9	11.30	11.44	11.37	11.37	11.89
Means	11.30	11.40	11.31	11.34	11.85

ELEMENTS.

It will be evident from an examination of Table IV that neither the maxima nor the times called T_o follow at regular intervals, yet the inequalities in the periods do not exceed a few days. Considering the short and long maxima separately, a least-square solution made in 1899, when the maxima from No. 3 to 13 were available, gave the elements:

J. D.

No. 1 { For short max., $T_o = 4039.0 + 107^d.745\ E + 1^d.095\ E^2$
{ For long max., $T_o = 4080.4 + 112^d.58\ E + 0^d.74\ E^2$,

in which E is the epoch number. In deducing these elements the observed dates were assumed as the zero epochs, and the only unknowns were the coefficients of the first and second powers of E. Using the maxima Nos. 3 to 19, and introducing

a term for the correction to the zero epoch, we deduce the following elements:

J. D.

No. 3 { For short max., $T_0 = 4033.8 + 113^d.29\ E + 0^d.20\ E^2$
For long max., $T_0 = 4080.0 + 114^d.73\ E + 0^d.17\ E^2$.

A comparison of the observed dates with these two sets of elements is given in Tables VIII and IX, in which the first column gives the epoch number; the second and third columns give respectively the observed times, T_0, and the intervals; the fourth and fifth columns give the dates as calculated by Elements No. 1 and the residuals in the sense observed minus computed; the sixth and seventh columns the corresponding quantities for Elements No. 3. The first set of elements are seen to represent the observed times fairly well as far as Epoch 6, after which the

TABLE VIII.

RESULTS FOR SHORT MAXIMA.

E	Observed		Calculated			
			Elements No. 1		Elements No. 3	
	T_0	Int.	T_0	O-C	T_0	O-C
	J. D.	d	J. D.	d	J. D.	d
0	4039.0		4039.0	0.0	4033.8	+ 5.2
		106.4				
1	4145.4		4147.8	− 2.4	4147.3	− 1.9
		114.1				
2	4259.5		4258.9	+ 0.6	4261.2	− 1.7
		110.5				
3	4370.0		4372.1	− 2.1	4375.5	− 5.5
		121.4				
4	4491.4		4487.5	+ 3.9	4490.2	+ 1.2
		113.7				
5	4605.1		4605.1	0.0	4605.3	− 0.2
		116.5				
6	4721.6		4724.9	− 3.3	4720.7	+ 0.9
		116.4				
7	4838.0		4846.9	− 8.9	4836.6	+ 1.4
		115.0				
8	4953.0		4971.0	−18.0	4952.9	+ 0.1
		130				
	5083		5097.4	−14	5069.6	+13
		116				
	5200.5		5226.0	−27	5186.7	+14

TABLE IX.

RESULTS FOR LONG MAXIMA.

E	Observed		Calculated			
			Elements No. 1		Elements No. 3	
	T_0	Int.	T_0	O-C	T_0	O-C
	J. D.	d	J. D.	d	J. D.	d
0	4080.4		4080.4	0.0	4080.0	+ 0.4
		115.8				
1	4196.2		4193.7	+ 2.5	4194.9	+ 1.3
		111.0				
2	4307.2		4308.5	− 1.3	4310.1	− 2.9
		120.6				
3	4427.8		4424.8	+ 3.0	4425.7	+ 2.1
		110.6				
4	4538.4		4542.6	− 4.2	4541.6	− 3.2
		123.4				
5	4661.8		4661.8	0.0	4657.9	+ 3.9
		115.0				
6	4776.8		4782.5	− 5.7	4774.4	+ 2.4
		113.2				
7	4890.0		4904.7	−14.7	4891.2	− 1.2
		131				
	5021		5028.4	− 7	5008.5	+12
		114				
	5135.7		5153.6	−17.9	5126.1	+ 9.6

divergence becomes intolerable. The Elements No 3 represent the maxima of the cycle quite closely, the greatest differences O − C being + 5.2 and − 5.5 for the short maxima. The average difference for the short maxima is $2^d.0$ and for the long maxima $2^d.2$.

At the foot of each table are given two unnumbered epochs to show how the elements will represent the maxima which come after the end of the cycle and the reversal of the order. Bearing in mind that on account of this reversal the maxima are of the opposite kind from the heading of the table, it will be seen that the differences are all positive, that is, the maxima are delayed by about 12 days.

An interesting fact is brought to light by a consideration of the lengths of the periods of normal light following the different maxima. In the set Nos. 3 to 19 the long maxima were followed by normal periods of from 41 to 48 days, averaging 44.

The short maxima were followed by quiet periods of from 30 to 46 days, averaging 40 days. But after the reversal the long maximum No. 22 was followed by a normal period of 33 days, 7 days shorter than any of the above; and the short maximum No. 23 was followed by 53.5 days of normal light, 7.5 days longer than any short maximum in the previous set: so that the reversal is shown not alone by the time of maximum but also by the length of the following period of normal light.

The foregoing facts suggest many interesting questions which cannot be discussed in this paper. In *V. J. S.*, **34**, 316, Dr. Hartwig suggested a theory to account for the variations—a companion revolving in a very eccentric orbit—but such a system would seem to be unstable.

The light curve of *SS Cygni* bears a striking resemblance to that of the "Cluster Type," so interestingly treated by Professor S. I. Bailey in Vol. X, p. 255, of the ASTROPHYSICAL JOURNAL. Indeed, if No. 33 of Professor Bailey's list can be taken as a sample, whose time of rise was found by Professor E. E. Barnard to be only 15 or 20 minutes, the light curve is almost identical in proportions with that for the long maximum of *SS Cygni*.

All the published observations of maximum No. 1, which preceded the two successive short maxima Nos. 2 and 3, are consistent with the same anomalous form as No. 20, which preceded the two successive long maxima. It is hoped that any other observations made in January 1897 may be published or communicated to the writers.

The times of the coming maxima cannot be safely predicted with our present knowledge. Elements No. 3 represent a uniformly increasing period, but it is not unlikely that the increase will be checked or even changed to a decrease. If this is true, the maxima for the remainder of 1900 may occur about October 20 and December 15. It must not be supposed that the presence of decimals of a day in the elements is intended for the purpose of prediction. They are merely to represent the past maxima as closely as possible, and may be of value in comparison with similar elements deduced from future cycles of maxima.

August 1900.

THE AUXILIARY APPARATUS OF THE MILLS SPECTROGRAPH FOR PHOTOGRAPHING THE COMPARISON SPECTRUM.

By W. H. Wright.

In accurate spectroscopic work involving the use of comparison spectra, the design of the apparatus for introducing the comparison is one of fundamental importance, though it is governed by considerations of the greatest simplicity. While the requirements of the case are very generally understood, it may be well for the sake of completeness to mention them here. It is essential: first, that the pencils of rays from the two sources should practically coincide within the spectroscope; and, second, that the two spectra should be observed as nearly simultaneously as possible. The first consideration is always important, while the second becomes equally so when, as in the case of stellar spectrographic work, the exposures are long, and the temperature and position of the spectroscope are continually changing.

The usual practice of observers with stellar spectrographs is to limit the part of the slit devoted to the light of the star by opaque diaphragms, of one form or another. When it is desired to photograph the comparison spectrum, this portion of the slit is covered, the diaphragms are removed, and the comparison light is thrown through the exposed extremities. Precautions are taken to insure the complete illumination of the collimator lens by light from every point of the illuminated portion of the slit. In this manner the first condition is fulfilled, and by distributing the exposures to the comparison spectrum symmetrically in point of time with regard to the middle of the exposure, the second is approximately satisfied. The method has been found very practicable. It has, however, some objectionable features, among which may be mentioned the following: first, the various adjustments usually require considerable time, so that in general it is not expedient to interrupt the star exposure

more than once for the purpose of introducing the comparison; and, second, the mechanism near the slit requires some handling during the operation, and is therefore liable to occasional accidental jarring. Another method, adopted for a time by an eminent observer, was to place the source of comparison light permanently at some distance in front of the slit. This enabled him to use it at frequent intervals during the exposure to the star, but allowed only an incomplete illumination of the collimating lens.

In many cases a totally reflecting prism has been used as a convenience in throwing the artificial light into the collimator; but one of its most valuable properties, that of allowing the collimating lens to be simultaneously filled with light from two different sources, does not seem to have been taken advantage of in the construction of stellar spectrographs. With a view to utilizing this property, the slit mechanism of the Mills spectrograph has been somewhat modified. While formerly the effective length of the slit was limited by opaque diaphragms as mentioned above, this is now done by two prisms so placed as to throw artificial light into the collimator.

As the plan has worked in a most satisfactory manner, it may be well to give a few of the details of the new mechanism, though these have been controlled largely by the construction of the old apparatus. The essential features are shown in plan in the upper part of Plate XX, the lower part giving a sectional view through the collimator and slit. $s\,s'$ is the slit, P, P', are reflecting prisms mounted on sliding carriages c, c'. These carriages are operated by a right and left-handed screw M, by means of which the effective slit may be adjusted to any desired length. L, L', are condensing lenses of 19 mm focus, which form images of the iron electrodes I, I', at i and i'. The angles at i and i' are 49°, and the lines $I\,L$ and $I'\,L'$ make angles of 8° with the slit plates, which therefore do not interfere with the converging pencils from the lenses.

In order to accommodate the change in focal length of the thirty-six-inch objective, due to variation of temperature, the

collimator tube and slit must be moved in the line of collimation. The supports for the electrodes and condensing lenses are therefore attached to the collimator tube instead of the framework of the instrument. The construction of the apparatus allows for all necessary adjustments.

In order to insure the complete illumination of the collimator lens, the image lenses L, L', have, as is usual in such cases, been given a diameter larger than that theoretically required. The actual aperture is 9 mm, while the theoretical aperture is 2 mm. To test the collimation adjustment of the comparison apparatus, a cap having a central aperture of 1 mm is placed over one of the image lenses (and then the other), the corresponding electrode in each case being sparked. If under the circumstances any light passes through the spectroscope and partially illuminates the camera lens, or what amounts to the same thing, forms a spectrum too bright to be due to diffused light from the reflecting prisms, the adjustment is considered sufficiently accurate, and the cap is removed.

Every adjustment of the apparatus is made once for all, and the exposure is given by merely passing the spark. The diaphragms used formerly to limit the effective length of the slit are well adapted to regulating the length of the lines of the comparison spectrum, when this is considered desirable. The apparatus is lightly constructed, the weight being about nine ounces.

A more or less ideal condition in the use of the spectrograph might seem to be one which allowed the exposure to the comparison to continue during the entire interval of the star exposure. The light of the comparison is, however, usually much brighter than the starlight, and there are other practical difficulties in the way of the realization of such a condition. In fact, there is a certain advantage in photographing the comparison at intervals, to which attention has been called by a number of observers. If the several exposures to the comparison are not allowed to overlap, data are furnished for detecting the amount of shifting of the spectrum during the exposure. The exposures

with the Mills spectrograph may very conveniently be given in four sets.[1]

1. The brighter lines on one side of star spectrum.
2. " fainter " " other " " " "
3. " fainter " " first " " " "
4. " brighter " " second " " " "

In determining the times at which these exposures should be given it has been convenient to assume that the position of a line varying as the result of continuous changes of temperature, flexure, etc., in the instrument may be expressed in terms of the first three powers of the time, as follows:

$$x = a + bt + ct^2 + dt^3 ; \qquad (1)$$

x being a distance measured along the spectrum from some fixed point on the photographic plate, and t being the time. In work of the character considered, the plates are usually rapid and the exposures not above normal, so that to a certain degree of approximation, other things being equal, the photographic effect of light may be considered as proportional to the time of exposure. Upon this assumption the mean position of a line of wave-length λ, exposed from $-\frac{1}{2}T$ to $+\frac{1}{2}T$ (T being the interval of exposure to the star) is

$$x_0 = \frac{1}{T}\int_{-\frac{1}{2}T}^{+\frac{1}{2}T} x\,dt = \frac{1}{T}\int_{-\frac{1}{2}T}^{+\frac{1}{2}T} (a + bt + ct^2 + dt^3)\,dt = a + \frac{c}{12}T^2 . \qquad (2)$$

This should coincide with the position resulting from the mean of the four exposures actually given. As there are roughly 50 per cent. more lines in the second and third exposures than in the first and fourth the former have been given weight 3 and the latter weight 2. Assuming a distribution of exposures symmetrical in point of time with regard to the middle of the star exposure, the times may be represented by

$$-\tau_2 , \; -\tau_1 , \; +\tau_1 , \; +\tau_2 .$$

Let the corresponding positions of a line of wave-length λ be

$$x_1 , \; x_2 , \; x_3 , \; x_4 ;$$

[1] See CAMPBELL, this JOURNAL, 8, 139.

then $$x_0 = \frac{1}{10}(2x_1 + 3x_2 + 3x_3 + 2x_4);$$

or, by (1),

$$= a + \frac{c}{5}(3\tau_1^2 + 2\tau_2^2);$$

which, by (2), results in

$$\tau_2^2 = \frac{5}{12}T^2 - \frac{3}{2}\tau_1^2. \qquad (3)$$

Either τ_1 or τ_2 may now be assumed, and the other determined by this relation. It will be seen by making $\tau_1 = \tau_2$ that the assumed conditions can be satisfied by two exposures; but since a variation more irregular than that assumed in (1) would be corrected for in a better manner by a greater number and a more uniform distribution, the general practice has been adopted of giving four exposures, assuming $\tau_1 = \frac{1}{8}T$. In case of short exposures, τ_1 is assumed to be zero, and the exposures are given in three sets.

The apparatus was placed on the Mills spectrograph with the approval of Dr. Campbell, to whose suggestions a number of the details are due. It has been in operation for three months, and its performance has been most satisfactory. Among its chief advantages are the following:

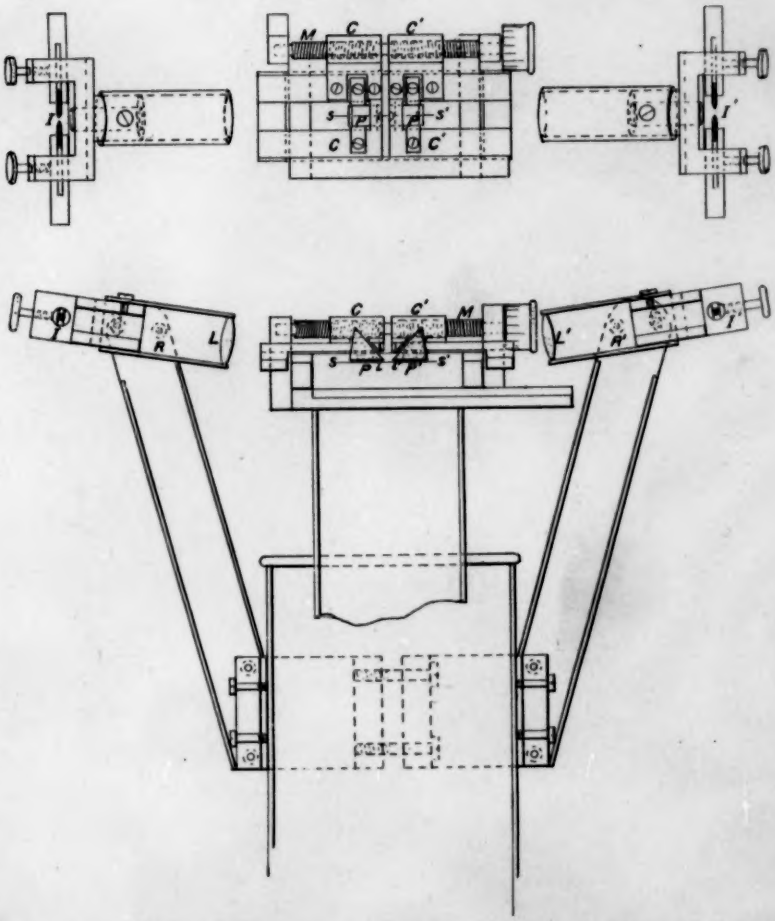
1. It allows the comparison spectrum to be photographed at will, without interrupting the exposure to the star.

2. It is always in adjustment, and therefore effects a saving of time and trouble.

3. The slit remains undisturbed during the entire exposure, and is therefore not liable to accidental displacement.

LICK OBSERVATORY, UNIVERSITY OF CALIFORNIA,
September 1900.

PLATE XX.



COMPARISON SPECTRUM APPARATUS FOR THE MILLS SPECTROGRAPH.

"A SUGGESTED EXPLANATION OF THE SOLAR CORONA."

By Sir William Huggins.

Professor Scheiner, in a paper bearing the above title[1] makes the statement:

. . . . that the opinion seems to have been general that this incandescence (of solid or liquid particles) arises in a manner similar to that of shooting stars and meteors from friction in the outer solar atmosphere (p. 25).

And further on he says:

The idea that the cause of the incandescence of the meteoric particles in the neighborhood of the Sun is to be found in the direct solar radiation is so obvious that it is surprising that it has not hitherto been expressed in the literature of the subject—at least I have been unable to find anything of the sort (p. 26).

For the sake of historical accuracy it seems to me to be desirable to point out that in my Bakerian Lecture on the corona of the Sun, given before the Royal Society in 1885,[2] the view taken of the corona was inconsistent with the meteoric friction hypothesis, and, indeed, the incandescence of the solid or liquid particles was attributed directly to the "enormous radiation" of the Sun to which they are subjected. I will confine myself to two or three short extracts.

. . . . These considerations appear to me to be of great weight in support of the view, that though some meteoroid and some cometary matter may fall into the Sun, the corona consists essentially of matter coming from the Sun (p. 124).

. . . . The corona must, therefore, consist of a fog in which the particles are incandescent, and in which the gaseous matter does not form a continuous atmosphere . . . . A fog, even so extremely attenuated, would probably be fully sufficient to give rise to the corona under the enormous radiation to which it is subjected (p. 122).

[1] This Journal, 12, p. 25. [2] *Proc. Roy. Socy.*, 1885, p. 108.

The main conclusions at which I had arrived in 1885 were summed up in my Presidential Address of 1891[1] in the following words:

> In a discussion in the Bakerian Lecture for 1885, of what we knew up to that time of the Sun's corona, I was led to the conclusion that the corona is essentially a phenomenon similar in the cause of its formation to the tails of comets—namely, that it consists for the most part probably of matter going from the Sun under the action of a force, possibly electrical, which varies as the surface, and can therefore in the case of highly attenuated matter easily master the force of gravity even near the Sun. Though many of the coronal particles may return to the Sun, those which form the long rays or streamers do not return; they separate and soon become too diffused to be any longer visible, and may well go to furnish the matter of the zodiacal light, which otherwise has not received a satisfactory explanation (*loc. cit.* p. 11).

The results of the bolometric examination of the inner corona by Mr. Abbott, under the direction of Mr. Langley, during the recent total eclipse of May last, showing that its light does not contain the predominance of infra-red rays usual in the spectra of hot bodies; and on the other hand the successful photography by Mr. Newall of Savart bands in the coronal light where the Fraunhofer lines were very feeble, have opened questions of interest as to the view we should take of the coronal matter. We await the new information on these points which we may reasonably expect from the long duration of the total eclipse of next year.

LONDON,
September 26, 1900.

[1] *Report Brit. Assoc. Adv. Sci.*, 1891, p. 1.

THE PROBLEM OF THE DAYLIGHT OBSERVATION OF THE CORONA.

By R. W. Wood.

Shortly after the eclipse of May 28 it occurred to me that the strong continuous spectrum of the corona might furnish a means of mapping its form in full sunlight by some method utilizing the light *within* some broad Fraunhofer line of the sky light close to the Sun. I found, however, on looking over the literature on the subject, that this method had been most thoroughly tried by Professor Hale with his spectroheliograph, unfortunately without results. It then occurred to me that possibly a more sensitive method would be to look for traces of polarization within the dark lines.

So far as I know, no one has attempted to devise any method depending on coronal polarization for the detection of the Sun's corona in full daylight. At first sight the method seemed quite hopeful. The sky light close to the Sun was found to be quite free from polarization, when examined with a Savart plate which is capable of showing 1 per cent. of polarized light, while observations which I made with the same instrument at Pinehurst last May convinced me that the coronal polarization may amount to 15 per cent. or even 20 per cent. Through the courtesy of Professor Campbell and the Regents of the University of California, the facilities of the Lick Observatory were placed at my disposal during the past summer for as long a time as I chose to devote to the problem. A further study of the conditions, however, convinced me that the plan was almost hopeless, nevertheless on account of its importance I resolved to make at least a few preliminary experiments. The results were negative as I had expected, but a record of the work may suggest a more hopeful method to some more skillful experimenter.

I had decided to limit myself at the start to a search for traces of polarization in the light of the sky close to the Sun.

Once having accomplished this, the designing of a recording instrument for mapping the corona would doubtless present no great difficulty.

My original plan was to form an image of the sky immediately adjoining the Sun on the slit of a spectroscope in such a way that the plane of polarization of the corona would coincide with the plane of the slit. A Savart plate placed in the eyepiece with a Nicol prism would then show, if properly adjusted, dark bands crossing the spectrum at an angle of 45° with the Fraunhofer lines, provided the light contained 1 per cent. or more, of polarized light. I scarcely hoped to find the bands crossing the bright parts of the spectrum, but thought it possible that they might be detected within some of the broad lines, if the rest of the spectrum were screened off. A fundamental objection to the plan occurred to me, however, before I even commenced experimenting. The polarized light of the corona must be reflected sunlight. The unpolarized may be in part emitted and in part reflected. The polarized portion should then have a spectrum similar to sunlight, *i. e.*, containing the Fraunhofer lines. We should not then expect polarized light corresponding to the wave-lengths of these lines to be present, or in other words we should not expect to find traces of polarization within the dark lines.

There is, however, a factor which may modify this condition. If the reflecting particles have any considerable to-and-fro motion in the line of sight the reflected waves will be altered in length by Doppler's principle, and the change in wave-length in the case of light reflected under certain conditions is double the change effected on emitted light. It thus appears possible that internal motion in the corona may be operative in effacing the Fraunhofer lines. The breadth and haziness of the 1474 coronal line in some of Professor Campbell's photographs indicate the possibility of such internal motion, though certain conditions of pressure and temperature may be all that is necessary to give a line of this appearance. Assuming the absence of the Fraunhofer lines to be due to internal line of sight motion we

might hope for traces of polarization within the dark lines of the sky light.

The few experiments that I made gave negative results, but my time was limited, and I still think it barely possible that with suitable apparatus something might be accomplished.

I was unable to find any data regarding the residual light within the lines of the Sun's spectrum. There must of course be some, for it is hard to conceive the absorption as complete. Added to this light would be the light *emitted* by the coronal particles in virtue of their incandescence. The amount of this may, however, be smaller than would appear at first sight. Assuming internal motion, I see no reason why we should attribute the continuous spectrum to incandescent solid or liquid particles.

Unquestionably matter, as near the Sun as the coronal particles, must be at a high temperature, but I am inclined to think the reflected light would be vastly in excess of the emitted. So far as I know, no data exist regarding the ratio of the reflected and emitted light of a body brought to a state of incandescence through exposure to radiation. Whether laboratory data would have much value or not I do not feel prepared to say, so much would depend on the wave-length of the exciting radiations. In the extreme case of Tyndall's dark heat focus, all the visible light would be emitted. On the other hand a small object placed in the focus of an immense burning glass exposed to sunlight, shines principally by reflected light.

The chief experimental difficulty that I have found is one that was anticipated from the start, namely the polarizing power of the prism. I have been unable to find any dispersing piece that does not polarize. Even a Rowland metal grating gives strongly polarized spectra. In the case of prisms, as we increase the dispersion we increase the polarization by the addition of new surfaces. The spectrum of the Mills spectrograph we found could be almost extinguished by a Nicol prism.

A direct-vision prism seemed to be the best for the work. The one that I used at Pinehurst polarizes only about 5 per cent.

of the transmitted light, and this can be corrected by a plate of glass placed in a plane at right angles to the plane of the prism's face, and inclined at the proper angle. By this device the Savart bands could be made to disappear entirely from the spectrum. Whether there were maxima and minima within the Fraunhofer lines it was impossible to tell on account of the narrowness of the lines. Higher dispersion would have weakened the light too much, besides introducing more polarization than could be conveniently compensated. Possibly a photographic method might show them. If the spectrum were screened off with the exception of a single line, a plate moved at a right angle to the direction of the line might reveal the presence of maxima and minima as "trails" of light and shade. It might even be possible to use a dense photographic negative of the spectrum as a screen and in some way utilize the light inside of all of the dark lines. I fear, however, that very great difficulties would be found in working with such an integrating screen.

In addition to the work with the spectroscope, an attempt was made to detect traces of coronal polarization in the region immediately adjacent to the Sun. If the corona contained 20 per cent. of polarized light and the sky light superposed on it was not more than twenty times as bright as the corona, the Savart plate placed in the eyepiece of a telescope should give a feeble indication of the presence of the corona. The object-glass must receive no direct sunlight, since in this case a large amount of light is sent into the eyepiece from specks and bubbles in the glass.

To secure suitable conditions a small telescope was set up in the shadow of a tall iron smoke stack, which barely hid the disk of the Sun. Not a trace of the Savart bands were to be seen, however. I have been unable to find any consistent data regarding the relative brilliancy of the coronal and sky light. One observer records it, if I remember right, as 1 to 500. My own estimate, based merely on observation, would put it much lower than this, but it is certainly high enough to mask all traces of

polarization, at least in such instruments as are at our disposal at the present time.

One other point occurs to me in connection with the subject. Some observers claim to have detected the Fraunhofer lines in the spectrum of the corona. Usually they are not seen, however. Possibly this may be explained by the polarization of the reflected light. Let us consider the coronal light to be chiefly emitted light, with a small amount of reflected light, as is usually assumed. The reflected light only will exhibit the Fraunhofer lines, and this light is strongly polarized. Now the dispersing piece can act as an analyzer as well as a polarizer. Suppose the slit of the spectroscope to be placed tangentially. The plane of polarization will then be at right angles to the slit, the oblique faces of the prism will consequently transmit these radiations, and the Fraunhofer lines may appear in the spectrum.

If, however, the slit be placed radially, the plane of polarization will be parallel to the slit, and the prism faces will almost completely reflect the polarized light and the dark lines will consequently be absent.

Janssen in 1871, and Stone in 1874, both working with a tangential slit, observed dark lines. Mosely in 1877, and Burton in 1890, with slit tangential saw no distinct continuous spectrum, owing doubtless to too high dispersion.

Other observers, working with a radial slit, found no traces of the lines.

Professor Campbell showed me a photograph of the corona's spectrum which he made at the Indian eclipse, beautifully sharp and clear, but without a trace of a dark line. He worked with a tangential slit.

These cases, which are all that I have found in which the slit's position is recorded, are in accord with the above theory of the absence of the lines. It seems to me that it would be well at the next eclipse to work with a tangential slit provided with a Nicol prism. By setting the Nicol in the proper position the polarized light would be wholly transmitted, while the

unpolarized, or emitted light would be reduced in intensity by one half. This change in the ratio of the intensities might be sufficient to show the dark lines very distinctly. By turning the prism through an angle of 90° the dark lines would vanish. If a grating is used the slit should be radial, since in this case we work with reflected light.

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OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF MAY 28, 1900, AT ARGAMASILLA, SPAIN.

By H. DESLANDRES.

TOTAL eclipses of the Sun, during the few seconds of totality, afford the only known opportunity to study the *corona*, which is the highest and most extensive part of the solar atmosphere, and the *reversing layer*, a region at the base of this atmosphere and of the chromosphere which is so thin that hitherto it has never been possible to observe it in full sunlight, even with the most powerful telescopes.

I planned to study these two important parts of the Sun, giving special attention to phenomena hitherto unknown. I made careful preparations for: first, the determination of the velocity of rotation of the corona by the spectroscopic method, which I was the first to apply for this purpose in 1893; second, (*a*) the examination of the ultra-violet spectrum of the corona, in the second or more refrangible region (from λ 3500 to λ 3000), which is absorbed by ordinary glass, and which I was the first to obtain, though in an incomplete manner, in 1893; (*b*) the examination of the ultra-violet spectrum of the reversing layer in the second region, not hitherto attempted; third, the study of the heat spectrum of the corona (not hitherto attempted) in a region far beyond the red; this study, as will be seen below, is important in connection with subsequent researches on the corona; fourth, the direct photography of the corona with slow plates of very fine grain.

In carrying out this program I enjoyed the aid of seven assistants, one of whom brought with him a chronophotograph kindly loaned by M. Marey.

Rotation of the corona.— For this investigation I used three spectroscopes of high dispersion, a visual spectroscope with grating, and two photographic spectroscopes having two and three flint prisms respectively. The displacements and velocities

were measured by the method of inclined lines, which I devised for the study of the rotation of *Jupiter*, and of *Saturn* with its rings, and which may be used with a small solar image. The visual spectroscope was adjusted for the green coronal line; but this was not seen at first, as it was faint, short, wide, and diffuse. On the east side of the equator, the inclination seemed to correspond to a rotation more rapid than that of the disk.

The two photographic spectroscopes were arranged so that each might receive three solar images upon its slit. I obtained in this way the spectra (from λ 4800 to λ 3700) of six double sections or of twelve sections parallel to the solar equator and equally spaced on the coronal ring. The lines of the chromospheric gases and the continuous spectrum are fairly intense on the negatives; but the coronal lines, which are essential for a study of the rotation, are almost completely lacking, except at two points, where they attain the small height of 3′, and are well adapted for measurement. The faintness of the coronal lines at the period of the Sun-spot minimum has already been pointed out.

Ultra-violet radiation.— I mention first a small spectroscope of Iceland spar and quartz, giving a very bright spectrum, previously employed at Senegal, which was used to obtain the complete ultra-violet spectrum (height 15′) without details.

The most perfect optical parts of Iceland spar and quartz were reserved for two cameras of 0.50 m and 1 m focal length with objective prisms; for while the slit spectroscope gives to better advantage the spectrum of a given point, the objective prism gives the spectra of all points at once.

With these two cameras ten photographs were obtained which give: (1) the entire ultra-violet spectrum of the reversing layer, including the half already known, from λ 4000 to λ 3500, and the half not hitherto recorded, from λ 3500 to λ 3000; (2) the entire ultra-violet spectrum of the upper chromosphere, not hitherto observed by the classic method of Janssen and Lockyer; (3) the entire spectrum of the corona, with two complete rings due to two new coronal radiations.

The above photographs required a long exposure, on account of the faintness of the extreme ultra-violet rays; they therefore could not show the curious and rapid changes in the spectra of the solar and chromospheric crescents.

I supplied this deficiency, thanks to M. Marey, who very kindly loaned me for a few days one of his chronophotographs, with movable film. The apparatus was attached to a train of four objective prisms of crown glass, giving the ultra-violet spectrum from λ 3800 to λ 3500. In two minutes it supplied as many as five hundred successive pictures 2 cm long and 3 cm wide, which clearly show the progress of the phenomenon. One of these photographs shows the complete series of at least twenty-four ultra-violet hydrogen lines, which is so remarkable on account of the mathematical regularity of the spacing.

Mention may also be made of a camera provided with an objective grating and adjusted for the green coronal line; this gave only chromospheric arcs, with no trace of the coronal ring, thus supplying additional proof of the faintness of the lines of the coronal gases.

Heat radiation.—I have already pointed out the special importance of the heat rays for the study of the corona. For the blue light of the sky, which hides from us the stars and the corona, is rich in very refrangible rays, but must be poor in rays of small refrangibility. An eye sensitive to only the extreme infra-red rays would see the stars in full daylight, and I have announced that the detection of the corona without an eclipse depends upon the photography of images with the heat rays. But it is desirable to find whether the corona strongly emits these rays.

I prepared special apparatus comprising a large silvered mirror of short focus for projecting the solar image, a slit spectroscope with crown prism, and a very sensitive Melloni pile with a Deprez-d'Arsonval galvanometer. The pile received only infra-red heat from the region near λ 13000.

On the day of the eclipse, before, during, and after totality, measures were made of the heat radiated from the center of the

Moon, and from points in the sky at distances of 3′, 6′, and 20′ from the Sun's limb. The heat at the center of the Moon decreased progressively until it reached zero at totality; and at this moment points in the corona 3′ and 6′ from the Sun's limb gave deviations of 5 and 3 scale divisions. These same points, without an eclipse and for the same altitude of the Sun in a very transparent sky, have at times given deviations of 11 and 7 divisions. The heat of the corona was thus half of the total radiant heat.[1] This simple experiment clearly indicates the possibility of obtaining the corona without an eclipse by means of the heat rays.

Direct photography of the corona.—This was accomplished only with small telescopes of 1.10 m, 0.40 m, and 0.30 m focal length, as the Meudon Observatory could not place at my disposal the large objectives of its collection. But the negatives were made on slow plates of fine grain and can be greatly enlarged. On some of these plates the equatorial streamers extend two diameters from the Sun.

The numerous instruments described above were carried by an old 8-inch equatorial and by two equatorial mountings, one of wood and one of metal, constructed especially for the eclipse. The last mentioned, of metal, is at once light and stiff, and includes certain special features. It carries large tables, readily accessible from all sides, on which instruments can be arranged as easily as upon a laboratory table. This design may be recommended for astrophysical investigations.

In closing, I may add that the duration of totality was found to be five seconds less than the calculated duration.

[1] With the ordinary luminous rays the ratio between the light of the corona and that of other points in the sky, under ordinary conditions, is very different. In the green-yellow, the intrinsic light of the corona is at most the fortieth part of the light of the sky under ordinary conditions, according to recent photometric measures. Hence arises the almost absolute impossibility of obtaining the corona without an eclipse with the visible rays.

Reviews

AN ATLAS OF REPRESENTATIVE STELLAR SPECTRA.[1]

The prominent part played by the Tulse Hill Observatory in the development of astrophysical research renders the appearance of its first volume of *Publications* an event of unusual importance. It is difficult for those who are acquainted through experience with the spectroscopic progress of only one or two decades, to realize the state of the science at a time when the light of a star had never been subjected to searching analysis. At present it seems a simple matter to attach a spectrograph to a powerful telescope and photograph the spectrum of a star. But the ability to do this was not achieved at a single stroke: it is the result of a long series of experiments dating back to the first work of Sir William Huggins at the Tulse Hill Observatory in 1862.

At that period, when object-glasses were smaller, telescope mountings less stable, and driving-clocks less efficient than those of the present day, the task of observing the spectrum of a star must indeed have appeared a formidable one. It is true that Fraunhofer, at the beginning of the century, had examined starlight with a prism placed over the object-glass of a telescope, and had even been able to detect differences among stellar spectra which, though not understood by him, have since proved to be of fundamental importance. But the plan deliberately chosen by Sir William Huggins was one much more difficult of realization. Recognizing the fact that the objective prism would not permit the use of a comparison spectrum, which is indispensable for the measurement of wave-lengths in stellar spectra, he resolved to attach an ordinary laboratory spectroscope to the eye-end of his 8-inch telescope. The star image must then be made to fall on the slit, where it must be accurately maintained as long as the spectrum remained under observation. Furthermore, as the image of a star is practically a point, its spectrum is linear, and must be broadened

[1] *Publications of Sir William Huggins' Observatory*, Vol. I. By Sir William and Lady Huggins. London: William Wesley & Son, 1899.

with a cylindrical lens, in order to render its character apparent. In spite of all difficulties, the observation was successfully made, in collaboration with Dr. W. Allen Miller, and in a short time it was possible to announce the presence in the stars of many well-known terrestrial elements.

It would be a pleasant task to follow through the first chapter of the volume as it recounts the many successes of the Tulse Hill Observatory's pioneer days. Here, for the first time, in August 1864, a nebula was found to give the spectrum of a glowing gas. Only two years later spectroscopic observations of the star which suddenly appeared in *Corona Borealis* revealed the presence of both dark and bright lines, some of the latter due to incandescent hydrogen. Then in turn came the first attempt to measure the motion of a star in the line of sight, the detection of hydrocarbon bands in the spectra of comets, and various researches in solar spectroscopy, particularly in the observation of the chromosphere and prominences without an eclipse. In 1876 a most important advance was made when the first photograph was secured of the spectrum of *α Lyrae*. This and other similar photographs included the invisible ultra-violet region, and for the first time brought to light the remarkable rhythmical spectrum of hydrogen. They also afforded material for a preliminary discussion of the evolutional order of the stars. A short time later the method of photographic registration was extended to the spectrum of the great nebula in *Orion*, and to the spectra of comets.

To the general reader this historical chapter, recounting the experiences of an amateur whose privilege it was to make discovery after discovery in an untried and almost unknown field of research, is likely to prove the most fascinating portion of a book which should do much to arouse interest in the New Astronomy.

Dr. Huggins' marriage, in 1875, secured for him (to use his own words) "an able and enthusiastic assistant," who has never since ceased to take a most active part in the observational and other work of the Observatory. Toward the preparation of the present volume for the press, Lady Huggins has contributed in large measure. In addition to the strictly scientific side of her collaboration, she has effectively decorated many pages with drawings of the Observatory and its surroundings, copies of old engravings, etc., inserted, for the most part, as chapter headings and initial letters. With these embellishments, the beautifully printed and bound book, with its broad margins and

attractive letterpress, affords an appropriate setting for its important contents.

The opening chapter, as already stated, contains a history of the Observatory and its work. Chapter II is a list of published papers. The next three chapters describe the instruments with which the photographs reproduced in the plates were made. Chapter VI, which is perhaps the most important section of the whole work, is devoted to a discussion of the evolutional order of the stars and the interpretation of stellar spectra. The valuable plate of historical spectra is described in chapter VII, and the text concludes with chapter VIII, in which the stellar spectra on the plates are given a preliminary discussion. These excellent half-tone plates, twelve in number, seem to bring out the details of the original negatives in an admirable manner. The authors have shown good judgment in using direct photographic reproductions, untouched by the engraver's tool. The slight loss of detail, which is inevitable in such cases, is more than compensated for by the perfect reliability of the illustrations, which never show more than the photographs themselves. The false lines, which seem to be unavoidable in enlargements of stellar spectra that have been widened vertically, are not seriously in evidence, and in most cases they can be easily eliminated on account of their fortuitous distribution, particularly since the spectra on a plate are generally so related that common lines can be traced from star to star. The wave-length scale accompanying most of the spectra will make the photographs far more useful than they would otherwise be.

The principal new contributions to stellar spectroscopy contained in the present volume are the photographs of the ultra-violet spectra of various types of stars, and the discussion of stellar evolution based upon them. These photographs have been taken with an 18-inch reflecting telescope, used in conjunction with a spectrograph containing two Iceland spar prisms.[1] Their importance will be recognized when it is remembered that they constitute practically our only source of information regarding the extreme ultra-violet region of stellar spectra. It is indeed rather surprising that in the years which have elapsed since the first photographs of stellar spectra were obtained in this very region, practically no advances have been made except at the Tulse Hill Observatory. The comparative scarcity of quartz or of

[1] For Sir William's original description of this spectrograph, see this JOURNAL, 1, 359, 1895.

Iceland spar prisms and well-mounted reflecting telescopes may perhaps account for this, but it is evident that a most promising field of investigation lies open at this end of the spectrum. Sir William and Lady Huggins have apparently not made extensive measurements of their negatives. A solar spectrum taken with the same instrument is employed as a standard of comparison for both wave-lengths and relative intensity. Two scales of enlargement are used for the illustrations. The smaller, 4¾ diameters, permits the entire range of the spectrum, from λ 4570 to λ 3300, to be included on a quarto page. The larger, 15 diameters, is used for the ultra-violet region only.

In entering upon a discussion of stellar evolution the authors, while premising that the great changes in stellar spectra from one type to another are due to loss of energy through radiation, lay stress upon the spectral differences which may result from the increasing force of gravity in the reversing region. They indeed think it possible that some of the spectral changes observed in stars whose temperature is rising as the result of condensation, may be due primarily to increasing density and in much less degree to higher temperature. The important question whether the diversity of stellar spectra may arise from original differences of chemical constitution is answered in the negative, after an interesting and convincing argument. Helium is very conspicuous in some stars, but it may be doubted whether it is wholly absent from those in whose spectra its lines do not appear. Our knowledge of the presence of helium in the Sun is due solely to the possibility of observing the bright line spectrum of the chromosphere. The remarkable variation in the intensity of the hydrogen and calcium lines in different stars is another case in point. But the strongest evidence is afforded by the gradual change in spectrum from star to star, and the possibility of forming unbroken series beginning and terminating in widely different types. This fact, taken together with the well-known difference between the spectra of the components of double stars, which may be assumed to originate from the same nebula, seems to amount to a demonstration that original differences of chemical constitution play no important part in determining the character of stellar spectra, unless such exceptional cases as that of the Wolf-Rayet stars must be accounted for in this way.

Passing now to the question of stellar classification, Sir William and Lady Huggins retain the commonly accepted view that the white stars represent the earliest stage of development. They select *Bellatrix* as

typical of the youngest stars, partly because of the fact that their photographs of the *Trapezium* stars in the Great Nebula of *Orion* show a similar spectrum. The order of succession of stars from *Bellatrix* through the solar stage and on through Vogel's class III*a* is easily traced. (Stars of Vogel's class III*b* and Wolf-Rayet stars are not considered in the present discussion.) The authors wisely refrain from introducing a new system of nomenclature for the various spectral types.

The extent of the ultra-violet spectrum has generally been considered a fair criterion of a star's effective temperature. As the extreme ultra-violet is most conspicuous in the spectra of the white stars, they have been held to represent not only the youngest, but also the hottest stage. After pointing out that Lane's law, according to which a gaseous mass must rise in temperature as it contracts in cooling, would seem to indicate that the highest temperatures must be sought in some class other than the first, the authors seek to test the question by the results of observation. Excepting *Sirius*, on account of its large parallax, most of the brightest stars in both hemispheres are at or near the solar stage. The authors conclude that, for the same distance and brightness, the effective temperature of a solar star must be much higher than that of a white star, on account of the far greater number of dark lines in the spectrum of the former, and their effect in cutting down the light. If, however, the solar star were of larger diameter than the white star, the equal effective brightness of the former might conceivably be due to the integrated effect of a greater number of less intense rays.

The investigations of Vogel, Langley, and others have shown that the general absorption of the solar atmosphere is much more pronounced for short waves than for long ones. The effect, then, of the increasing general absorption which may accompany the passage from the first to the second class would be to cut off the extreme ultra-violet spectrum. If the views of Sir William and Lady Huggins are correct, however, the position of maximum intensity in the spectrum advances toward the ultra-violet during this period of transition, attains its limit when the star is in some such condition as that of the Sun, and then retreats toward the less refrangible region as the temperature falls.

The difficulty of testing this conclusion arises not alone from the unequal effect of the increasing general absorption, but also from the presence of such a multitude of dark lines as the solar spectrum contains, not to speak of instrumental troubles and those that may be

due to our own atmosphere. It is evident that spaces between Fraunhofer lines must be selected for comparison with the broad regions of continuous spectrum in the white stars. The authors consider that the evidence of their photographs supports the new view. Just beyond the head of the hydrogen series the spectra of stars of the first class seem to fall off greatly in brightness, while the spectra of solar stars, though they do not extend so far into the ultra-violet, nevertheless appear to be stronger in this region when equally intense in the blue. Reproductions are given of several photographs made for the purposes of this comparison. Some of these seem to show the effect very clearly, notably in the case of *Capella* as compared with *Procyon* (Fig. 1). The original negatives, however, must be far more satisfactory than any form of reproduction for a delicate comparison of this kind.

Measures of the heat radiation of *Arcturus* and *Vega*, made by Professor E. F. Nichols at the Yerkes Observatory in 1898 and 1900, indicate that we receive from the former star (mag. 0.03) about twice as much heat as from the latter (mag. 0.19). As the two stars differ so little to the eye in brightness, this seems to indicate that the proportion of long heat-waves is greater in the spectrum of *Arcturus*. If the accuracy of the heat measures could be relied upon, if the important law $\lambda_{max.} \times T = \text{const.}$ could be considered to hold for both stars, and if the effect of increasing absorption were not most marked in the shorter radiations of the solar star, it might be fair to conclude that the maximum in *Arcturus* is displaced toward the red, and consequently that its effective temperature is lower than that of *Vega*—a result opposed to that reached by Sir William and Lady Huggins. So far as the reliability of the heat measures is concerned, it may be said, in spite of the minuteness of the observed deflections (about 0.3 mm for *Vega* and 0.6 mm for *Arcturus*), that a repetition of the measures of *Arcturus*, made in 1900, agrees remarkably well with the earlier results. Unfortunately *Vega* could not be reobserved this year. Again, while Paschen's law, which applies to the "black body," is not rigorously true for either star, it is at least safe to say that the maximum moves toward the red with falling temperature. The question of absorption is more doubtful. As the authors have pointed out, the marked effects of general absorption first show themselves far out in the ultra-violet, and advance toward the red as the temperature declines. So long as they are practically confined to the ultra-violet, however, they have no

bearing on the present case. The line absorption is also probably greater in the more refrangible than in the lower spectrum, though as yet we know nothing of the infra-red region of stellar spectra. As the photographs of stellar spectra upon which the authors base their opinion were taken with almost the only instruments in existence that may be considered suitable for the purposes of such a comparison, great weight must attach to their conclusions, even though they differ from commonly accepted views. Further measurements of heat radiation, and photometric observations in the visible spectrum, should throw some light on the question.

If space permitted, much more might be said of this interesting volume. The experiments on the changes in the calcium spectrum produced by varying the density of the vapor, and their bearing on both solar and stellar problems, will not be overlooked by astrophysicists. The extensive series of observations, both visual and photographic, of the spectrum of the *Andromeda* Nebula are of special importance in connection with Scheiner's recent work. The spectra of the *Trapezium* stars, and the excellent examples of the spectra of double stars, also deserve more than a passing reference. The same is true of the numerous spectra on the plates, which are of great service in tracing the course of evolution from star to star. Enough has been said, however, to indicate that the work should be in the library of every spectroscopist. As a means of arousing interest in astrophysical research, it should also be found in collections of books intended for general readers.

G. E. H.

Publicationen des Astrophysikalischen Observatoriums zu Potsdam. Photographische Himmelskarte. Band I. 1899.

THIS volume of over five hundred pages, which are of a somewhat larger size than those of the regular series of Potsdam publications, represents the first contribution to the great catalogue of stellar positions which forms the first part of the immense international undertaking known as the *Carte du Ciel* or Astrographic Chart. It may not be superfluous to allude briefly to the general scope and progress of the enterprise before proceeding to the specific volume in hand, inasmuch as the *Bulletin du Comité international permanent* does not appear to be very widely circulated.

Since the initial conference in 1887, chiefly organized through the efforts of the late Admiral Mouchez, subsequent meetings of the committee have been held in Paris in 1889, 1891, 1896, and 1900, which have been attended by numerous other interested astronomers upon invitation of the committee. A number of valuable memoirs have been published in the *Bulletin* of the committee, dealing with modes of obtaining, measuring, and reducing the plates, and much progress has been made in placing this branch of astrometry upon as firm a basis as any department of the subject. The two principal parts of the undertaking are (1) the production of the catalogue of the positions of all stars to the eleventh magnitude from measures upon the photographic plates and (2) the production of a photographic chart of the entire sky, upon a scale of 1 mm to 1′, or about two and one third inches to the degree. As the assignment of the zones to the various coöperating observatories has not been published heretofore in the ASTROPHYSICAL JOURNAL, the following list is given, as modified at the meeting of the committee in July:

Zone of Declination		Observatory	Zone of Declination		Observatory
+90°	to +65°	Greenwich	+ 4°	to − 2°	Algiers
64	55	Rome	− 3	− 9	San Fernando
54	47	Catania	−10	−16	Tacubaya
46	40	Helsingfors	−17	−23	Montevideo
39	32	Potsdam	−24	−31	Cordoba
31	25	Oxford	−32	−40	Undetermined
24	18	Paris	−41	−51	Cape of Good Hope
17	11	Bordeaux	−52	−64	Sydney
+10	+ 5	Toulouse	−65	−90	Melbourne

The photographic telescope of the Brothers Henry, of the Paris Observatory, was taken as the model, and accordingly the optical power of the different instruments is closely the same. The aperture is 34 cm and the focal length 343 cm, while the attached visually corrected guiding telescope has the smaller aperture of 23 cm, but the same focal length. There is considerable variety in the form of mounting of the telescopes. The plates are 16 cm square, and upon each, before exposure, a photographic impression is taken of the standard *réseau*, made by Gautier, which contains 26 numbered horizontal lines and an equal number of vertical lines, thus dividing the whole area of the plate into 676 equal squares of 5 mm side. The space within the *réseau*, 13 cm square, therefore contains 4.7 square degrees. For the purposes of the catalogue each star not fainter than the eleventh magnitude

will be twice photographed, the exposures, of about five minutes duration, to be so arranged that the star will once be near the center of the plate. The number of plates required from each of the eighteen observatories averages 1200. It is evident that the work of obtaining these plates, after the problem of the standard instrumental outfit and procedure had been settled, was slight as compared with the enormous task of measuring and reducing the plates, of determining accurately the magnitude of the stars, of comparing the results with other catalogues, and finally of publishing the completed work. In view of the great differences in the financial status of the different institutions, as well as in the amount of other work in their regular programs, it has been necessary to allow wide latitude to the participating observatories in most matters subsequent to the procurement of the plates. In general the reports at the recent conference indicate that the work has progressed well, two thirds of the plates for the catalogue having been already taken (nine of the observatories have completed their assignment), while nearly one fourth of the required number of plates has been measured. The work of making the chart plates, which will require exposures of half an hour or more, is naturally in a much less advanced state, although heliogravure reproductions of them have begun to appear from the Paris Observatory and from some others.

The sub-title of the volume under review is: 20627 *Scheinbare rechtwinklige Coordinaten von Sternen bis zur elften Grösse nebst genäherten Oertern für 1900.0. Bearbeitet von J. Scheiner.* It includes the measurements of fifty-seven of the 1232 plates to be obtained at Potsdam in its zone from 31° to 40° of north declination, expressed in terms of rectangular coördinates in units of the *réseau* interval, together with estimated magnitudes, the magnitudes and number in the Bonn *Durchmusterung* of stars occurring therein, and the approximate right ascensions (to nearest second) and declinations (to tenths of minutes of arc) for 1900.0 of all the stars.

The immensity of the whole undertaking appears when we note that at this rate some twenty more volumes of this size will be required to contain the corresponding results for the remainder of the Potsdam plates. If it should later be decided to convert these rectangular coördinates into accurate mean right ascensions and declinations for a given epoch, by the application of the necessary corrections for the scale and orientation of the plate, for refraction, aberration, precession, etc., then still another series of large volumes will be required.

The reasons are given why this was not undertaken by the Potsdam Observatory, as it will be on the part of certain of the coöperating institutions. A staff of five or six additional computers would be required aside from the present required services of two assistants, two computers, and the supervision of Professor Scheiner; but such increase would seriously limit the work of the institution in its principal field, astrophysics, and the production of a star catalogue is not at all within the normal scope of the Observatory. Aside from this, however, in the present state of astronomy the meridian-circle positions of those stars on a plate which had been included in the *Astronomische Gesellschaft* catalogues, and upon which the reductions to right ascension and declination would have to depend, are not nearly adequately accurate in comparison to the measures on the plate; hence the superiority of the latter would be of no advantage until some future re-observations and re-reductions of these meridian positions shall much increase their precision.

A description is given of the photographic refractor, and of the routine of obtaining the photographs. The measuring machine is also described and the procedure of measuring the plates. It appears that when the measurer dictates the micrometer readings to a recorder (which was the regular practice at Potsdam) somewhat over thirty stars can be measured per hour on the average.

The accuracy of the measure in the volume is discussed in a section of the introduction. Two settings in each coördinate were made upon each star image and upon each side of the *réseau* square. From a comparison of these the probable errors of the mean of the settings is deduced for the two observers at the measuring machine, Dr. A. Schwassman and Miss Alice Everett, and is found to be (mean for the two observers) $\pm 0''.07$ in R. A. and $\pm 0''.06$ in Dec. The probable error of the rectangular coördinates is best obtained from a comparison of the positions of stars occurring upon two different plates. Thus three pairs of plates, having in common respectively 13, 24 and 150 stars yielded these probable errors: $\pm 0''.14$ (R. A.) and $\pm 0''.13$ (Dec.); $\pm 0''.15$ and $\pm 0''.18$; $\pm 0''.19$ and $\pm 0''.17$. Professor Scheiner believes himself justified in adopting the simple mean of these, $\pm 0''.16$ and $\pm 0''.16$, as representing the measure of accuracy of the rectangular coördinates in the volume. The personal errors of setting of the two observers received attention, but were not as accurately determined as was desired.

The question of the magnitudes of the stars in the catalogue is obviously a difficult one, involving the still undiscovered law of the relation of exposure time to photographic impression. Overlooking Pickering's previous researches on the subject, the committee had originally innocently supposed that the increase in intensity of the star image would be directly proportional to the time, and that therefore only from ninety seconds to two minutes of exposure would be required for stars of the eleventh magnitude, inasmuch as the stars of magnitude 9.0 and 9.5 in the *B. D.* were readily obtained in about thirty seconds. After considerable discussion and experimentation with absorbing screens of wire network, it became apparent that about five minutes was the necessary exposure time for the eleventh magnitude stars, and this has been pretty generally employed by the participators.

No general legislation was adopted governing the determination of the magnitudes fainter than the ninth, except that they should be brought into relation with some existing system of magnitudes. For this that of the *B. D.* would naturally suggest itself, in spite of the uncertainty of its estimates of the 9.5 and tenth magnitudes. In the work at Potsdam, where the plates are only taken on clear nights and when the region photographed is near the zenith, the assumption has been made that the faintest measurable objects are of magnitude eleven; and the magnitudes between this point and the ninth (taken from the *B. D.*) are directly interpolated. The magnitudes were not determined by measurement of the diameters of the star disks, but by simple estimation to quarters of a magnitude; the accordance of these estimates is about the same as that of the ordinary eye estimates of the *B. D.* It will be interesting to know in how far the measures of the star disks in progress at some of the observatories yield more accurate results. A table in the introduction, obtained from a comparison of all stars of the *B. D.* found on the plates, gives the corrections necessary to reduce the photographic magnitudes to those of the *B. D.*, arranged for each plate according to magnitude. In some cases these corrections run as high as a magnitude, but for the most part are much less.

An interesting discussion is given of the comparison of the numbers of stars in equal areas of the plates and of the *B. D.* The least number of stars on a plate is 40, of which 37 are contained in the *B. D.*; the greatest number is 1830, of which 156 are found in the *B. D.*, so that the ratio of numbers of stars varies from 1.1 to 11.7. It appears

from a comparison of the plates of sparsely occupied regions of the sky with regions thickly occupied that the ratio of the "star density" between the Potsdam catalogue and the *B. D.* increases nearly proportionally to the star density itself. This discussion has elsewhere been published and need not be further considered here.

An important feature of the work has been the careful comparison with the places of the *B. D.* All stars of the *B. D.* not found on the plates, or differing more than 4^s in R. A. or $3'$ in Declination, were especially looked for and in most cases found as very faint objects. In case of objects then outstanding Professor Deichmüller, of Bonn, undertook the careful examination of the original MS. records of the B. D., the results of which are given in detail at the end of the list of measures on each plate.

In the catalogue the plates so far measured are taken up in succession, in order of R. A. within a given zone of 1° Dec., but as this volume contains plates whose centers were on the parallels $+32^\circ$, 33°, 34°, 35°, 36° and 37°, the sequence in R. A. is often interrupted. At the head of each plate's list are given: the date and time of the exposure; the temperature, barometric pressure, and focal setting of the instrument; the steadiness and transparency of the air; the R. A. and Dec. of the origin of the coördinates for that plate (center of the *reséau*); the position and magnitude of the guiding star employed; and the name of the observer at the telescope and at the measuring machine.

A summary at the end of the volume shows the areas covered by the different plates, with the pages on which they are to be found, which would prove to be very necessary in the practical use of the work.

The question of the immediate utility of the volume here considered, in its present form, is perhaps an open one. The approximate R. A. and Dec. of all the stars included make it of the greatest value as extending the Bonn *Durchmusterung* to stars of the eleventh magnitude, and reduction tables are given which make it possible to convert the rectangular coördinates into R. A. and Dec. with an approximation perhaps sufficient for most comparison stars for comet observations. But the convenient arrangement of the *B. D.* is wanting, and when the zone here considered is completed it will be necessary to consult a somewhat voluminous index in order to find the volume which includes the plate covering the area in which a star is sought. Until the zone

is completed a reference to the work may require the examination of all the volumes that have appeared at the time.

Hence, and especially in view of the insufficient accuracy of the meridian circle positions of the fainter stars, the full value of the accurate measures of these volumes is not likely to be available for many years. E. B. F.

Strahlung und Temperatur der Sonne. Von J. SCHEINER. Leipzig: Englemann, 1899.

IN its convenient compass of one hundred octavo pages this interesting essay treats of the various radiations received from the Sun, and of its temperature. The investigation of the radiations is quantitative rather than qualitative, and theoretical rather than experimental. No consideration is here given to the nature of the radiations as revealed by the spectroscope, and no extended descriptions of actinometers or other instruments for measuring the radiation are included. The book contains neither illustrations nor diagrams, and no unnecessary array of formulæ, although there is no avoidance of those essential to the subject. More than one half of the volume is devoted to the thermal radiations from the Sun, while the luminous, chemically-active, and electro-dynamical radiations can be treated in about eight pages. The first section briefly considers the absorption by the Earth's atmosphere, and an appendix of fifteen pages deals with the diameter of the Sun.

The most valuable part of the work is the discussion of the temperature of the Sun in the light of the recent important theoretical and experimental researches on the law of radiation of the black body by Lummer and Pringsheim, W. Wien, Paschen, and others, many of which have appeared in the pages of this JOURNAL. In his usual luminous style the author examines the validity of the laws of radiation of Newton, of Dulong and Petit, of Stefan, and of others, and shows that Stefan's fourth-power law is the best founded both on theory and experience, so that its use seems fully justified in the extrapolations necessary in application to the Sun.

The formula employed for obtaining the effective temperature of the Sun, the meaning of which term is carefully explained, is

$$x = 273 \cdot \sqrt[4]{\frac{2.48}{\sin^2 \frac{\phi}{2}} \cdot \frac{s}{h_1}}$$

where ϕ is the angular diameter of the Sun, s is the solar constant, h_x is the amount of radiation from a black body at 100° to another at 0°, and the factor 2.48 is $\left(\frac{373}{273}\right)^4 - 1$. Adopting 4.0 gram-calories per square centimeter per minute as the most probable value of the solar constant, based upon the most reliable determinations, and using Kurlbaum's value of $h_1 = 1.056$, the effective temperature of the Sun is found to be 7010°, absolute. Should the smaller value of $s = 3.75$ be preferred, the temperature will be 6900°.

The apparently hopelessly irreconcilable determinations of this temperature by various early observers, whose values ranged through millions of degrees Centigrade, are now shown to be surprisingly accordant when reduced by Stefan's law. Those so reducible are

Pouillet	5600°
Secchi	5400
Violle	6200
Soret	5500
Langley	6000

To these may be added the measures of Rosetti, reduced by his own empirical law and yielding a result of 10,000°; and of Paschen, who employed empirical corrections to Stefan's law, and obtained 5000°. The reviewer has excluded the value of 6200°C. given for the measures of Wilson and Gray, and reduced by them according to Stefan's law, as Professor Scheiner evidently had not seen their article in full as published in *Philosophical Transactions* for 1894. In this they adopt Ångström's larger estimate of the terrestrial absorption, and increase their number from 6200° to 7400°C. In a later communication to this JOURNAL (August 1899) they give reasons for increasing the latter value by 30 per cent., stating that an experimental investigation is in progress for clearing up this point.

It is evident that the principal outstanding uncertainty at present is due to the atmospheric absorption, and the value of 7000° adopted above allows most liberally therefor, whence its larger value. In order to obtain the true effective temperature of the photosphere, however, the absorption in the solar atmosphere must be taken into account. Considerable space is therefore given by Professor Scheiner to a statement of the work by different observers on this subject. He adopts the rounded figure 1.5 as the amount by which the solar radiation would be increased if its atmosphere were removed; so that the solar constant

would thus be increased 50 per cent., rising to 6.0 gram-calories, and the effective temperature of the photosphere would become 7760° Abs. It would seem to the reviewer safe to adopt the value of 1.7, which has been actually found for thermal radiations, in place of the factor 1.5, but this does not much affect the result, yielding almost exactly 8000°, or 7730°C. It thus appears, as is at once seen from the formula, that even a considerable change in the solar constant will produce but little effect on the final temperature, since s is under the radical.

Quite as interesting as this section is the succeeding one, on indirect methods of determining the solar temperature. Here the reader who has not had time to follow the researches of Wien, Lummer and Pringsheim, and Paschen, will find a clear statement of their results and their bearing upon this and other related problems of radiation.

Further sections deal with secular and periodic variations in the solar temperature, the former of course leading to a brief presentation of Helmholtz's contraction theory, and the latter to an allusion to the studies on the effects of Sun-spots on terrestrial meteorology.

The appendix treats, in a somewhat less satisfactory manner, of the unsatisfactory question of the solar diameter. Professor Scheiner adopts as most probable the diameter of $31' 59''.26 \pm 0''.10$ obtained by Auwers from a full discussion of the numerous determinations of the solar diameter made on the occasion of the last transit of Venus.

Professor Scheiner's essay is especially to be commended to the attention of teachers, who are likely to find its perusal profitable to a degree quite disproportionate to its size, and who can then supply or correct the omissions or misstatements in regard to the solar temperature which occur in the chapters on the Sun in most of our text-books of astronomy.

E. B. F.

Observations of Variable Stars by Argelander, Schönfeld, and Schmidt. Annals of the Astronomical Observatory of Harvard College, Vol. XXXIII, pp. 29–134.

In this volume Professor Pickering has given a careful reduction and discussion of a large part of the observations of long period variables made by these distinguished astronomers, using photometric magnitudes of the comparison stars, thus insuring a uniform system and furnishing a basis for comparison with later work.

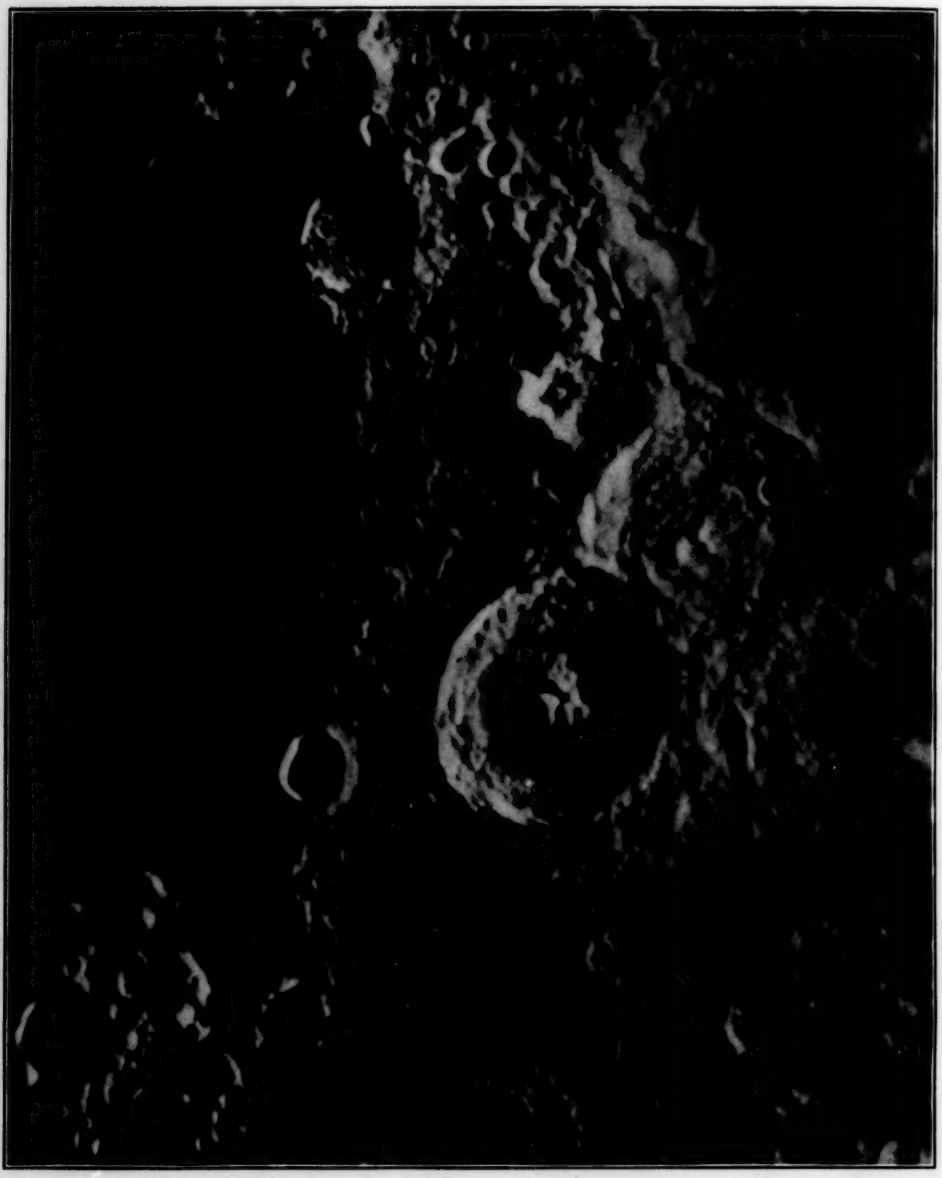
The observations by Argelander include those published by him in Vol. VII of the Bonn *Beobachtungen*, and in addition about 4000 unpublished comparisons made in 1869–1871. The value of one "grade," expressed in photometric magnitudes, was found to be 0.14, and seems to be independent of the magnitudes of the comparison stars or of the intervals covered. Following a table giving the designation, position, and magnitudes of the comparison stars for each of sixteen variables, comes a list of the individual observations, giving the Julian and calendar dates, the adopted magnitude, and the residuals from the comparisons with different stars.

The observations by Schönfeld are given in a similar form. They relate to thirty-two variables of long period, and were made between 1853 and 1859. The value of one "grade" is 0 092 of a magnitude. The individual results are given both in grades and photometric magnitudes.

The observations made by Schmidt were copied from his manuscript at the Potsdam Observatory, and that part published which relates to thirteen variables of long period, mostly naked ·ye stars. "Aided by the favorable climate of Athens, he was enabled to observe stars night after night, thus securing a continuity of measures such as can be obtained at few other observatories." Unfortunately the value of the work is lessened by Schmidt's failure to leave on record the data for identifying the comparison stars used; out of eighty-two relating to the thirteen variables, only thirty-four could be identified, and some of these are still uncertain. The relative brightness of the comparison stars was determined from Schmidt's observations, and the series adjusted to the photometric scale when possible. About 7000 individual observations, thus reduced, are published, made between 1845 and 1879.

J. A. P.

PLATE XXI



LUNAR CRATER THEOPHILUS AND SURROUNDING REGION

PHOTOGRAPHED WITH 40-INCH VISUAL TELESCOPE AND COLOR-SCREEN BY G. W. RITCHEY